BITING FORCE IN MAN

MEASUREMENTS UNDER CONDITIONS OF PHYSIOLOGICAL FREE WAY SPACE BETWEEN THE TEETH

BY

FOLKE STRENGER
L. D. S. D. M. D.
STOCKHOLM, SWEDEN

1949

BITING FORCE IN MAN

MEASUREMENTS UNDER CONDITIONS OF
PHYSIOLOGICAL FREE WAY SPACE
BEETWEEN THE TEETH

BY

FOLKE STRENGER
L. D. S. D. M. D.
STOCKHOLM, SWEDEN

AKADEMISK AVHANDLING

SOM MED NÅDIGT TILLSTÅND AV KUNGL. MAJ:T OFFENTLIGEN FÖRSVARAS INFÖR MEDICINSKA FAKULTETEN I UPPSALA Å ANATOMISKA INSTITUTIONENS HÖRSAL TORSDAGEN DEN 19 MAJ 1949 KL. 10 F. M.

STOCKHOLM 1949

AKTIEBOLAGET FAHLCRANTZ' BOKTRYCKERI

Digitized by the Internet Archive
in 2026

https://archive.org/details/IA41550014_0005

BITING FORCE IN MAN

MEASUREMENTS UNDER CONDITIONS OF PHYSIOLOGICAL FREE WAY SPACE BETWEEN THE TEETH

BY

FOLKE STRENGER
L. D. S. D. M. D.
STOCKHOLM, SWEDEN

STOCKHOLM 1949

AKTIEBOLAGET FAHLCRANTZ' BOKTRYCKERI

300/50

R. UNIV.
BIBLIOTHEEK
LEIDEN

CONTENTS

Preface 7

Introduction ..... 9—10

Chapter I. Historical Survey of Measurement of the Force by Biting.

A. Extraoral Measurement ..... 11—17

B. Intraoral Measurement ..... 17—21

C. Theoretical Calculations by Wustrow and Winkler 21—22

The Author's Investigation

Chapter II. Physiological Conditions for Measuring the Force by Biting ..... 25—28

Chapter III. Construction of Measuring Apparatus ..... 29—35

Chapter IV. Method of Measuring

The Determination of the Degree of Hardness of Lead (the Constant of Force) ..... 36—42

The Curvature Radii of the Cusps ..... 42—47

The Shape of the Surface of the Impressions ..... 47—49

Determination of the Force by Measuring the Depths of Impression ..... 49—51

Meyer's Relation ..... 51—53

Error of Measuring ..... 53—54

Chapter V. Practical Application of the Method of Measurement

Variability of Force ..... 55—58

Investigation of 10 Test Cases ..... 58—60

a) Occlusive Biting in Group ..... 60—61

b) Occlusive Biting by Single Teeth ..... 61—63

Occlusive Biting in Group. 36 Cases ..... 63—64

Discussion ..... 64—67

Measurement of the Force by Biting in Cases of Periodontal Disease and in Cases of Complete Denture Cases ..... 67—73

Chapter VI. Comparison between Earlier, Intraoral Measurement and the Author's Own Measurement ..... 74—79

Summary ..... 80—86

Literature ..... 87—90

PREFACE.

This work has mainly been performed to construct an apparatus for measuring the biting force by man under physiological conditions, and with this construction to determine the exerted force.

I wish to express my sincere thanks to Professor *David Holmdahl* and Professor *T. Teorell*, Uppsala, for the great interest they have shown in this investigation.

To Professor *H. Hallendorff*, Professor *O. Svahn* and Civilingeniör *H. Lindberg* at the Royal Institute of Technology, Stockholm, I owe a deep gratitude for the kind interest and the most valuable help with the arrangements for these experiments.

I have to thank Professor *Bo E. Ingelmark* and am very indebted to Dr. phil. *P. E. Wretblad* for the most valuable information on technical problems, Docent *L. Goldberg*, Amanuens *E. Blomgren* and Dr. *Gösta Rydberg*, L.D.S., for valuable discussions and information of various kinds.

To Dr. phil. *Ragnar Holm*, who gave me the first information in measuring impressions, my warm thanks.

The translation and proof-reading have been carried out by Mr. and Mrs. *Hogg;* my thanks to them.

For the technical assistance of Ingeniör *L. Pehrson* and Ingeniör *E. Lundin* at Statens Provningsanstalt, Stockholm, my best thanks.

INTRODUCTION.

In respect to function and load each organ has a certain limitation. These limitations can be registered to a certain extent, and in the odontology such a registration is of great importance. It is a valuable help in planning of treatment to have an approximate idea of the capacity of the teeth and their surroundings to divide and carry the force by biting. An examination for this purpose does not only show the distribution of a maximal load but also the functional limit of the biting apparatus.

Thus a study of the force by biting and its distribution is of fundamental interest whenever restorative or paradontal treatment is planned.

In orthodontics also this problem is of great importance, even though very little is known about the changes in the force by biting during childhood. It should be a task of the future to make a thorough investigation of the variations of the force by biting in the child, the adult and the aged.

In a rest position of the mandible the teeth do not meet before the mandible is moved into centric occlusion. In articulating movements the force by biting must be divided according to the conception of a balanced set of teeth. To study this it is necessary to have a device, which does not disturb the joint or the movements of the mandible and which registers the total force and the components on each tooth simultaneously. The total biting force is the resultant of the force by biting. How should that be defined?

According to *Riechelmann* (1920) the force by biting is the total force of those biting muscles which move the lower jaw upwards.

Normally the force represents only part of the muscle power. The force by biting is estimated in proportion to the muscular cross-sections.

Fick and *Ed. Weber* have claimed these areas to be 40 sq.cm. Since the average force by biting is calculated approximately as 10 kg. per sq.cm., the total muscle force is 400 kg. As mentioned above, only a fraction of this power is utilized during normal biting.

The relatively great force exerted during the chewing of food requires organs and tissues that can withstand heavy loads. The maxillary bones thus embody in their architecture the principle of a lightweight structure with a maximal resistance to the force by biting. Several processes as well as the hard palate absorb and divide the load, so that the brain and other organs are protected.

The mandible is sturdily built and can endure the most varying strains.

G. V. Black (1914) has shown that extracted teeth easily carry a load greater than the one used by biting.

CHAPTER I.

HISTORICAL SURVEY OF MEASUREMENT OF THE FORCE BY BITING

A. *Extraoral measurement.*

Measurement of the biting force is mentioned for the first time in literature by the Italian *Borelli* in 1681. The author loaded the open mandible with weights suspended on a thread coil over the molars, and the biggest load that was lifted was considered equivalent to the force by biting. This varied from 60 to 200 kg.

A similar method was used by *Sauer,* Berlin 1891, who exchanged the thread coil for a metal plate, the ends of which were loaded. The average result was 25 kg.

In 1893 the Americans *Patrick* and *Dennis* demonstrated the first instrument for measuring the force, called a "gnathodynamometer". Its construction was defective but later improved by *Black,* Chicago. The instrument consisted of a compressible spring with pointer and graduated scale (Fig. 1).

This construction was the prototype of similar measuring apparatuses made by *Dieck, Berten, Hentze, Morelli, Haber* and others.

Patrick reported the average value to be about 75 kg., and *Dennis* measured the force of the incisives to be from 7 to 12.5 kg., the premolars from 11.3 to 18 kg., and the molars from 14.5 to 21.5.

Black was repeatedly occupied with the problem and gave, in 1895, figures between 13.5 and 122.5 kg., and in 1914 between 11 and 125 kg. The average figure was calculated to be 77.7 kg.

A. Schröder, 1895, made use of a lever arrangement registering the force at different distances between the jaws. No variation in the resulting figures could be proved either at short or long distances. The investigation included only adult men, and the force of the front teeth varied from 40 to 60 kg.

In the apparatus constructed by *Arnones,* Florence, only the total biting force of the jaws could be measured

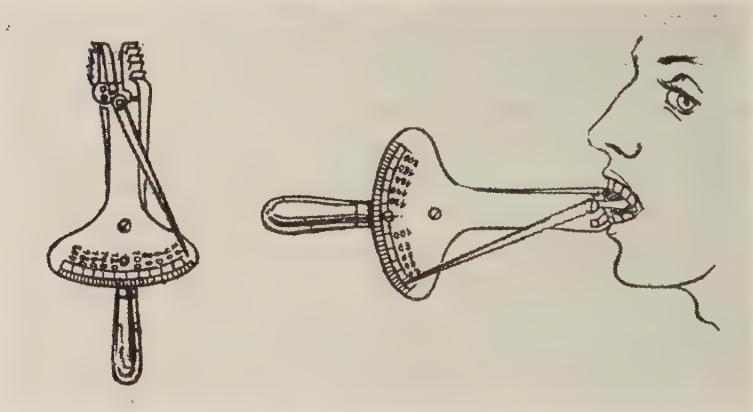


Fig. 1. *Black's* Gnathodynamometer. (After Haber.)

and consisted of two movable plates. Registration took place simultaneously on a graduated scale and a rotating graphic recorder, the latter giving an expression of the instantaneous force when closing the mouth. The author reported values from 3 to 100 kg., the average value being 25 to 30 kg.

Thourén, 1910, declared that the force between the incisives very seldom exceeded 30 kg. In one case the force between the canine teeth was 60 kg. and between the first molars 104 kg. The author maintained that the force between the first molars was three times as great as that between the incisives. Geometrically a still higher force would be expected at the wisdom tooth, but this has not

proved to be the case. The measurement was made with a specially constructed "Statmos"-balance.

Eckerman, 1911, presupposed that the mandible was a one-armed lever with equal moments of a force, i. e. the same force needed for closing as for opening the jaws. In accordance with this principle the author measured the

Fig. 2. *Eckermann's* Gnathodynamometer. (After Eckermann.)

force necessary to open a closed mouth. The apparatus looks like a pair of tongs of which the one limb is fixed in a stand connected to the dentist's chair, while the other is freely suspended and equipped with a graduated scale and sliding weight. When the resistance of the mandible was broken, the maximum biting force was considered reached. (Fig. 2.)

The author gives clear evidence by anthropometric research that the distance between mandibular joint and

wisdom tooth is half the distance between mandibular joint and incisal cross in the mandible. As force and distance are inversely proportional, so the force at the wisdom tooths is twice as great as at the incisives.

This hypothesis was made a gnathodynamometrical law. The method of calculating was described as follows:

If the force of the incisives is 1 or 10/10 it must be 20/10 at the wisdom tooth, 15/10 at the first molar and 17/10 at the second molar. In other words, if a value of 30 kg. is obtained at the first molar, the value at the incisives is $30 \cdot \frac{10}{15} = 20$ kg. and at the wisdom tooth $2 \cdot 20 = 40$ kg.

In about 200 cases investigated the force among women seldom exceeds 30 kg. at the front teeth and 60 kg. at the molars. For men the figures are 40 and 80 kg. The normal force of the incisives of women is not lower than 20 kg. and of men 25 kg.

Schwander-Lickteig, 1920, replaced the spring with a plunger enclosed in an oil-filled cylinder, which was connected with a manometer indicating the force.

Haber, 1926, was granted patents on three variations of the same measuring apparatus, which were all based on the principle of the spring balance. (Fig. 3.)

These patents were debated in odontological journals in 1926 and for many years after. The result of the debate was that the apparatus could be accepted, provided that it was not regarded as a precision instrument and that the values obtained were not expressed in kg., but the pointer on the scale only gave an indicative value which could be used as a basis of comparison between the conditions of different teeth.

H. Schröder, 1927, added to his lever apparatus biting plates of varied forms in order to measure the pressure of different teeth, at different positions of the mouth and with different loading surfaces.

The investigation also included measurements in cases where a local anaesthetic was used.

The author followed Eckermann's directions, but was unable to obtain the same regularity and exactitude.

In a table of five measurements, based on the force measured at the first molar, the author both calculated and actually measured the force developed at the pre-

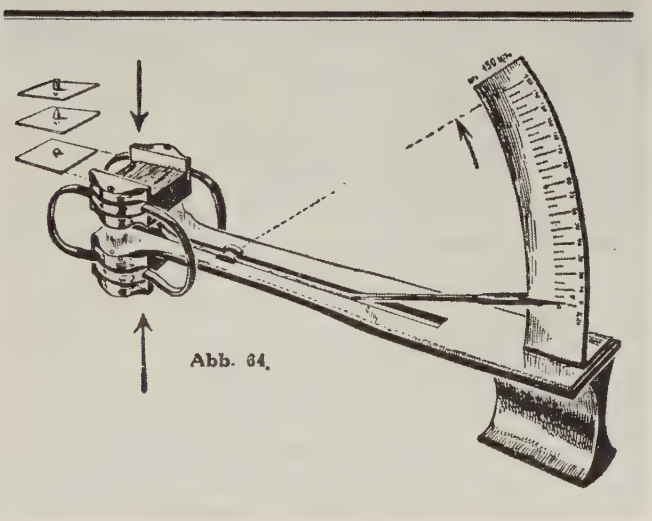


Fig. 3. *Haber's* Gnathodynamometer. (After Haber.)

molars and incisives. Higher figures were obtained throughout by actual measurement than by calculation, the difference at the premolars being about 3.8 kg. and at the incisives 1.3 kg.

The author also sought to determine to what extent the biting force was dependent on the size of the loaded surfaces. To find this out, different sections of the teeth were covered with metal bands, and with these in position biting tests were carried out in the gnathodynamometer. The figures were between 14.2—20.7 kg.

The measurement under a local anaesthetic showed

higher values. Thus a man of 21 normally exerted a force of 35 kg., and with local anaesthetic about 60 kg. In the latter case pain was caused in the region round the joint. Where teeth and tissues were diseased, the author found that values were lower owing to the diminished power of resistance.

G. Müller, 1928, constructed an apparatus on the same principle as Sauer's and obtained in the front 45 kg., at the first premolar 50 kg, between premolar and the first molar 60 kg., at the first molar 71.5 kg., and at the second molar 74. When these figures were compared with tests made with Haber's gnathodynamometer, they were found to be higher throughout.

Heinroth, 1928, tried by an instrument constructed on the lever principle to obtain values comparable with Haber's. His apparatus is similar to a modern letter balance, where the balance tray is replaced by two objects, on which to bite. Moreover there is a rotating cylinder for continuous graphic registration of the force developed during a given time, whereby the intensity of the bite can also be read.

A measurement lasting 15 seconds was illustrated by a diagram. The curve rises during the first two seconds up to about 30 kg., whereafter the force lessens during the following two seconds down to about 1 kg. This weak condition lasts barely three seconds, whereafter the curve rises in two seconds to a maximum of about 40 kg., only to fall rapidly to zero.

The Bimeter, invented by *R. Boos,* 1940, is an instrument designed to record the biting force of various positions and openings in the intermaxillary relation by construction of full denture. The centric relation is established with the aid of the gothic arch tracing, and a power point is located at the position assumed in the intermaxillary relation when registering the maximum power. The correct vertical height is determined by the maximum biting power for each patient.

The above investigations are the most important, but unfortunately the results cannot be compared. The apparatuses have been constructed on different principles, and are further defective in various ways, which has been confirmed by check readings.

The greatest difference may be found in the application of the bite on different surfaces, and at different distances between the biting planes. As the placing of the person and the position of the head affects the force values, the muscle force must also be affected thereby. A common definition of the force by biting is lacking — some consider the word equivalent to muscle capacity, while others make it synonymous with the power of the periodontal tissues to resist biting force.

B. *Intraoral Measurement.*

Intraoral measurement is based upon the *Brinell* test of the impressions obtained by biting on a soft metal plate and is an indirect measurement of the biting force.

The method of measuring the impressions is derived from the theory of strength in compression and is used in determining the hardness of a metal.

Hardness is defined as the resistance of a material to the force of another body pressing on its surface.

The test is generally carried out with help of spherical impressions. The *Brinell* test is made with a steel pellet of a given diameter being pressed into the object with a given load.

The diameter of the impression is measured, and the hardness number, also called the *Brinell number* or *Brinell hardness*, H_B, is either calculated or taken from a table, which gives the hardness H_B as the quotient between force P in kg. and the spherical impression area A in sq. mm.

$$\text{The Brinell formula: } H_B = \frac{P}{A}$$

H. Schröder—Schönwald, 1921, made use of the following apparatus. Silver bands were constructed for upper and lower jaw. A steel pellet was fixed on the upper band at the tooth, of which the force was to be measured, while its counterpart in the lower jaw was provided with a plane lead plate, on which the impact of the pellet was made (Fig. 4).

This construction was varied in order to determine also the biting force of individual teeth. The impressions were measured in a hardness test apparatus made by *Martens,* a modified form of the *Brinell* test. In this the depth was measured and the force registered. The distance between the jaws was at the commencement of the tests about 10 mm., the steel pellet occupying a space of 5 mm., the lead plate 3 mm. and the silver bands 2 mm.

The only measurement published is that on a youth of 16 by the first molar, as follows:

Biting force at	10	mm.	between	jaws:	39.125	kg.		
» » »	12.8	»	»	»	:	36.6	»	
» » »	15.25	»	»	»	:	23.125	»	
» » »	17.25	»	»	»	:	17.5	»	
» » »	20	»	»	»	:	12	»	

An attempt to explain these big differences is not made, but the authors are content with the hypotheses that the physiological force of the jaw is more fully exploited by intraoral measurement than extraorally by gnathodynamometers, and consider intraoral measurement according to this method completely reliable, corresponding to natural biting.

Laboratory tests for the sake of comparison are presupposed.

Köhler—Etling, 1922, used an almost identical method, but without silver bands on the jaws. A steel pellet of 5.73 mm. diameter was used, and the plates were made from a metal composition called "Reichszinn", about 2.3 mm. thick, 2 cm. long and 1 cm. broad. The pellet was fixed with sticky wax in the fissure of the tooth the force of

which was to be measured, and the plate was fixed on its antagonist with cement, while a metal plate served as foundation (Fig. 5).

The experiments were supplemented by series of laboratory tests. The steel pellet was fixed on a one-armed

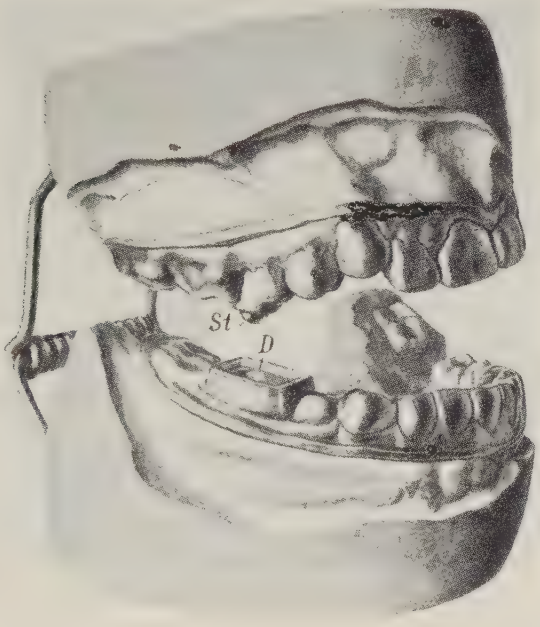


Fig. 4. *H. Schröder's* apparatus for intraoral measurement of the force by biting. (After H. Schröder.)

lever and after loading it with various weights the different spherical impressions could be determined. From these tests the force of individual teeth could be obtained. It was shown that the length of the biting time was without significance for the size of the impact.

The authors used the *Brinell* test invertedly, i. e. the force was derived from a given hardness number and the microscopically measured spherical impression, and is con-

sidered equivalent to the biting force. The figure values are taken from the tables of the loading tests made ex ore.

Of the ten cases described No. 4 is the most interesting, dealing with a young man of 18 without caries and with normal bite. Unfortunately only the right side was measured.

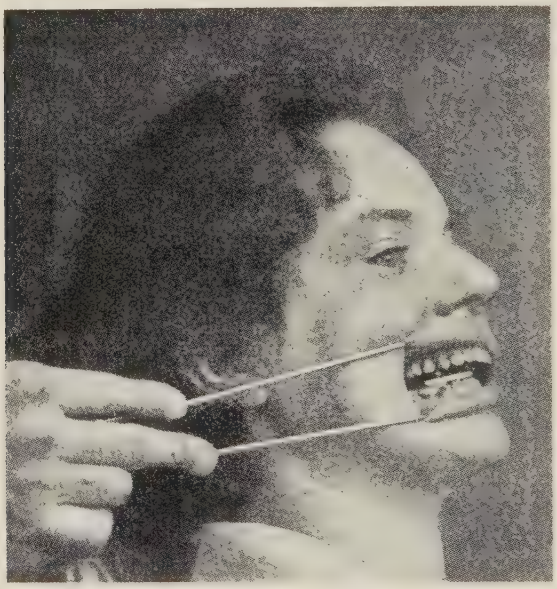


Fig. 5. *Köhler-Etling's* apparatus for intraoral measurement. (After Köhler-Etling.)

In this case steel pellets were applied on the separate teeth from the second molar to the first premolar, and the biting planes on the antagonists. (Time for biting 3—5 sec.) The distance between the jaws varied from 6—12 mm. The force measured by 7+ was 55 kg., by 6+ 60 kg., by 5+ 37 kg. and by 4+ 30 kg. In the incisives the force varied between 24—26 kg.

In another case, where all teeth in the upper jaw were filled, and further 6+ root-filled, a slight pain was registered at all bitings, the values varying between 26 –37 kg.

The highest values were obtained in a third case, where the figures were at 7+ 62 kg., at 6+ 47 kg. and at the premolars 52 kg. At the front teeth was measured 32 kg., all measurements being made at a distance of 6—10 mm.

C. *Theoretical Calculations by Wustrow and Winkler.*

In the historical survey the interesting theoretical calculations of the force by biting by *Wustrow,* 1919, and *Winkler,* 1922, may finally be mentioned.

Wustrow makes an attempt to determine mathematically the force by biting by obtaining the relation between the biting force and the surface load of the teeth.

The force by biting is divided into three components, the vertical, the sagittal and the transversal, which are sharply distinguished from one another, and by adding these together the total figure of load is obtained. The muscles which cause these three movements produce different values in proportion to their individual capacity and effect, and the values are calculated in relation to the width, thickness, length and position of the muscles.

The surface areas of the teeth are calculated by measuring the width of the teeth from one contact point to the other. This measurement is divided by 16, and each part is further divided by 8. According to the author this gives a gauge of the relation between the crosscuts of individual teeth.

The author further calculates the depth of the loaded surface and uses the same comparison figure as in measuring the width of the teeth.

Through adding the load from the different directions the total force by biting of individual teeth is obtained.

Winkler, 1922, calculates the biting force on the basis of Weber's research into the force capacity of the muscles per sq.cm., and after recalculating the anatomical position of the biting muscles in relation to the mandible, he establishes the vertical force of m. temporalis to be 80 kg.,

m. masseter 70 kg., and m. pterygoideus 30 kg. As the muscle force varies very considerably in different persons, the author obtains no absolute values but only a measure of the approximative force. The force by biting and the force of the joint in different types and positions of jaw, and in the different directions of the individual muscles, are calculated through construction of their different moments of a force. Observation is also made of the effect of the inclination of the teeth and of the occlusion curve, as also of the effect of the force for a symmetrical load and for one-sided biting.

The author finds that the relation of the muscle forces of m. temporalis, m. masseter and m. pterygoideus med. is 2.66 : 2.3 : 1, and the vertical masticatory force of the same muscles 1.6 : 1.2 : 1.

The aim of his whole investigation is to penetrate by theoretical means the anatomical and physiological conditions for measuring the force by biting.

THE AUTHOR'S INVESTIGATION

CHAPTER II.

PHYSIOLOGICAL CONDITIONS FOR MEASURING THE FORCE BY BITING

It was pointed out in the introduction that the biting force should be registered by an instrument, which indicates simultaneously *both* the total force within a certain area, e. g. 7—4, *and* the force of each individual tooth.

The instrument must be so constructed that it causes no change in the physiological courses of movement of the jaw joint and the mandible.

Measurement should take place in an area between the jaws which is defined by the rest position (the rest position of the mandible is established when the muscles of the jaws are in repose) and the position when the teeth have made contact in central occlusion.

When closing the mouth within this area, only a rotation of the condyle occurs, while a further opening of the mouth above the 3 mm. considered as normal gap causes a gliding movement which displaces the jaws in relation to one another.

Measurement must take place at the closing movement in the axial or vertical direction of the tooth. "It is in this direction that the root, the fascicular system of the root tissue and the hydraulic apparatus in the vascular system for equalisation of the pressure load are all adapted and formed, as is the architectonic shape of both alveolar and basal jaw bone" (Sundberg).

Measurement must be carried out at the end phase of biting, where the movement is vertical, i. e. in the direction parallel with the resultants obtained when the parallelograms of force of the biting muscles are combined. This

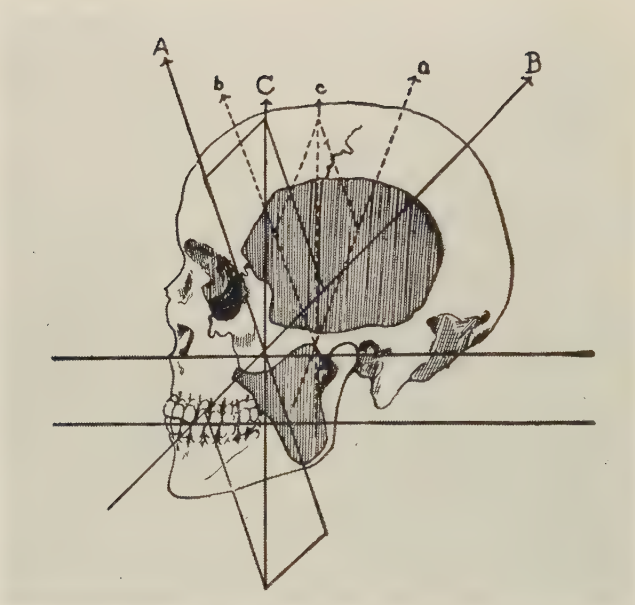


Fig. 6. "Parallelogram of forces as applied to the muscles by biting. A, direction of force exerted by the superficial portion of the masseter muscle. B, direction of force exerted by the posterior portion of the temporal muscle; b, direction of force exerted by the anterior portion of the temporal muscle; C and c indicate direction of resultant forces, that is, the force follows the diagonals of the parallelograms and is exerted in line with the long axis of the teeth. Of course, these directions are suggestive, not absolute." (After M. G. Swenson.)

phase is reached at the moment when the teeth meet in central occlusion.

When a rotation takes place in the jaw joint, a purely vertical movement without any gliding seems impossible to obtain, but if the distance to central occlusion is very small the gliding movement is hardly noticeable, and a measurement of it is very difficult to carry out.

Fig. 6, after Swenson, shows the method of constructing the parallelograms and resultants of force. The directions are, however, as the author points out, suggestive and not absolute.

There is also a possibility of determining the force developed in protrusive biting, i. e. in cases where the incisives meet edge to edge.

The third elementary movement — laterally — lacks a position which can be definitely defined, and is thus not measurable.

In order that the measurements may be of value and provide possibilities of comparison, it is necessary that the force developed should be measured simultaneously in both the right and the left halves of the jaw. Measurement of one side only cannot give acceptable results, as the division of force is different in the two halves of the jaw.

Kazis has shown this in his instructive treatise on "The forces and stresses of mastication", and the two following figures (Fig. 7 and 8) are constructed from drawings by this author.

From Fig. 7 it is obvious that the side, where the biting plane has been applied, exerts the greater force, and that the pivots of the two lever arms are on the same side.

Fig. 8 on the contrary shows the division of force when the biting planes rest on both sides of the jaws. Here the forces are equal, and the pivots are at an equal distance from one another on either side.

From the above the conclusion is drawn that it is impossible, through the cracking of nuts, to obtain a correct value of the force developed between the jaws and to identify this with the biting force.

Riechelmann confirms this in a series of tests, and points out that a nut shell is not cracked by one simple biting movement. The process is the result of an effort of final pressure, i. e. the nut is pushed between the molars and cracked through a general acceleration of force. There always remains however a surplus force, which is shown by the fact that the jaw stays in the same position after the cracking and does not immediately return to the occlusion stage, as might be expected.

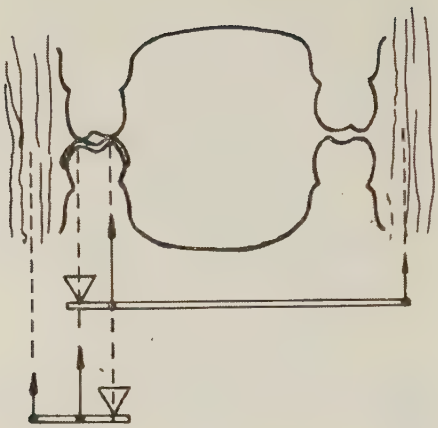


Fig. 7. Distribution of the force in one-sided biting.
(Drawing from Kazi's Fig. 23.)

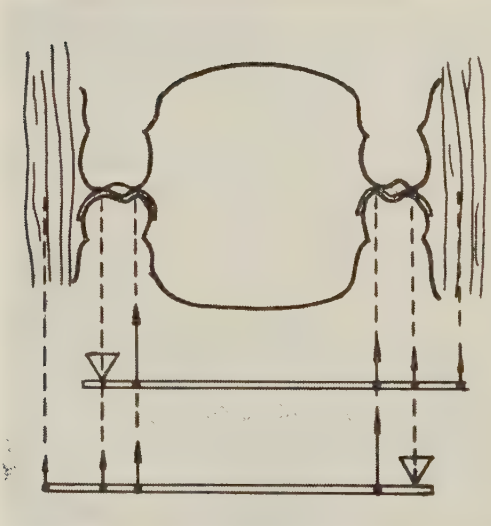


Fig. 8. Distribution of the force in biting on both sides simultaneously.
(Drawing from Kazi's Fig. 24.)

CHAPTER III.

CONSTRUCTION OF MEASURING APPARATUS

In order to test the latest practical experience in the sphere of measuring technique, a series of investigations and experiments were carried out in order to explore the possibilities of constructing an acceptable gnathodynamometer.

The following hypothesis was made for the carrying out of the work: — The measuring apparatus must register the forces of the different cusps, i.e. it must be possible to determine the individual force of each cusp. The apparatus must further be made in different sections, and each section must contain a measuring instrument. These sections must be constructed according to the anatomical shape of the teeth.

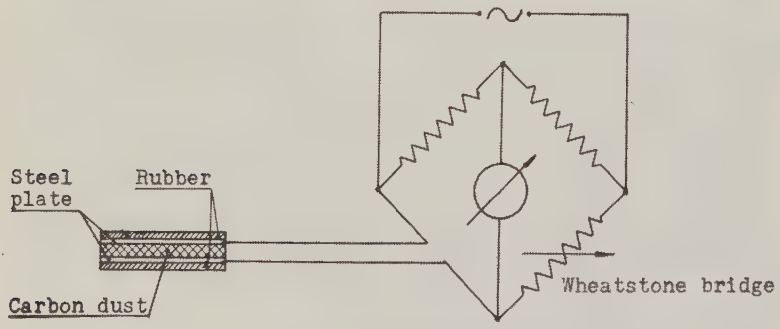


Fig. 9. Apparatus for extraoral measurement based on varations of resistance in layers of carbon.

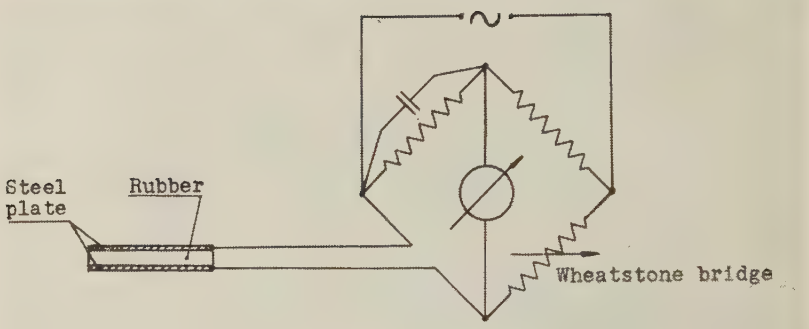


Fig. 10. Apparatus for extraoral measurement based on variations of capacity in a plate condenser.

The registration of the forces between the jaws at different sections must take place ex ore, and possibly be carried out in connection with a recording apparatus showing the course of excursions.

The first investigation (Fig. 9) was based on the variations of resistance in layers of carbon dust. The resistance consisted of two metal plates, between which was a layer of carbon dust. As an outer coating a thin layer of hard rubber was used. The apparatus was connected to a Wheatstone bridge. The variations of current in the diagonal were measured, and the variations of resistance and force were calculated. Calibration was carried out by measuring the current when the layer of carbon was loaded with known forces.

The second investigation (Fig. 10) aimed at measuring the variations of capacity in a plate condenser. The latter consisted of two metal plates separated by a rubber disc. Two methods were employed for determining the force: either measuring with a bridge as in the previous case, or by electron tube (on half the resonance curve). The apparatus was calibrated as in the previous case before and after each test.

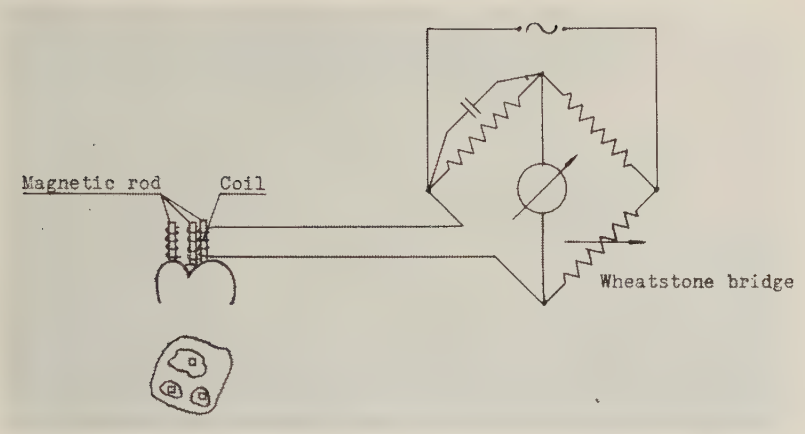


Fig. 11. Apparatus for extraoral measurement according to inductive method.

Another solution of the problem was tried by the inductive (magneto-elastic) method (Fig. 11). Coils wound around metal rods with special magnetic properties were placed against the highest points of the cusps. The action of biting caused an alteration in the magnetic properties of the rods through deformation, i.e. the inductance of the coil was changed. The coils were connected to a measuring bridge as in previous tests, and calibration was carried out as before.

This apparatus required a precise indication of the highest point of each cusp, so as to fit the rods in the correct positions. In order to solve this problem, the position of the teeth had to be mapped and necessary details established.

Through the cooperation of Mr. Percy Tham at the department of photogrammetry at the Royal Institute of Technology, this problem was solved, and the results have been published in Svensk Tandläkare-Tidskrift 1946, No. 1.

The stereometric map of the mouth with contour curves and characteristic high and low points is shown in Fig. 12 and 13. The constructor of the gnathodynamometer obtains

an accurate drawing, which enables him to place the measuring apparatus correctly and also gives him a clear picture of the extensions and limits of the different sections.

Apart from these experiments the possibility has also been discussed of connecting different sections to balloons filled with air or liquid, and of measuring the force developed in atmospheres.

The means of using hydraulic pressure invertedly was also considered.

All experiments however proved that it is at the present impossible to construct, for physiological requirements, an apparatus of such small dimensions and yet capable of such divergent registrations. The varying forms and sizes of jaws, teeth and cusps render the construction of a universal apparatus impossible.

In addition, such a complicated machinery, containing as it does a system of sections with both internal and external wiring, can be easily damaged and also be irritating for the person examined. A thorough inspection and calibration of the instrument before and after each test would take too long and be too cumbersome. Finally, an apparatus of such a kind would be very expensive, and though the measuring instruments could be used continuously, its "skeleton" with the different sections must be constructed afresh for each case.

The negative results of the above-mentioned experiments forced the author to try a new method of intra-oral measurement, viz. a method based on mechanical tests of the hardness of a metal, i.e. a Brinell-test.

A disadvantage of earlier experiments, performed by some investigators using the principles of this method, was the obstruction to biting caused by the thickness of the steel pellet and the biting planes. The jaw joint was forced out of its physiological course, and a rotation took

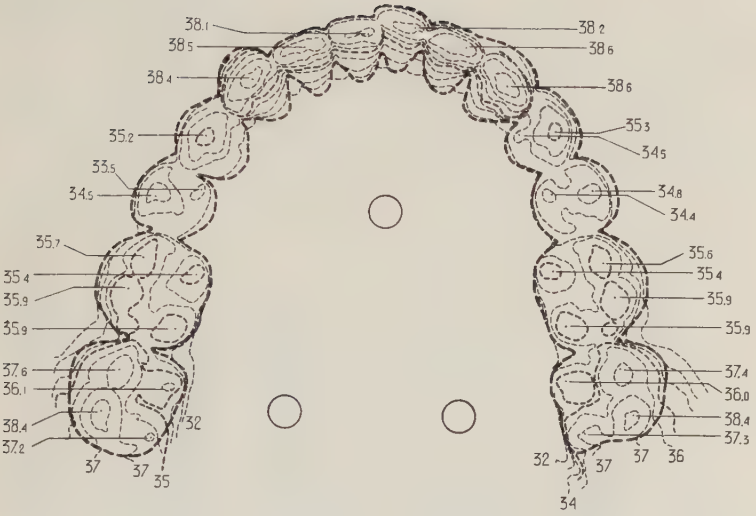


Fig. 12. "Map plotting" of lower jaw. The equidistance of the contour lines is 1 mm.

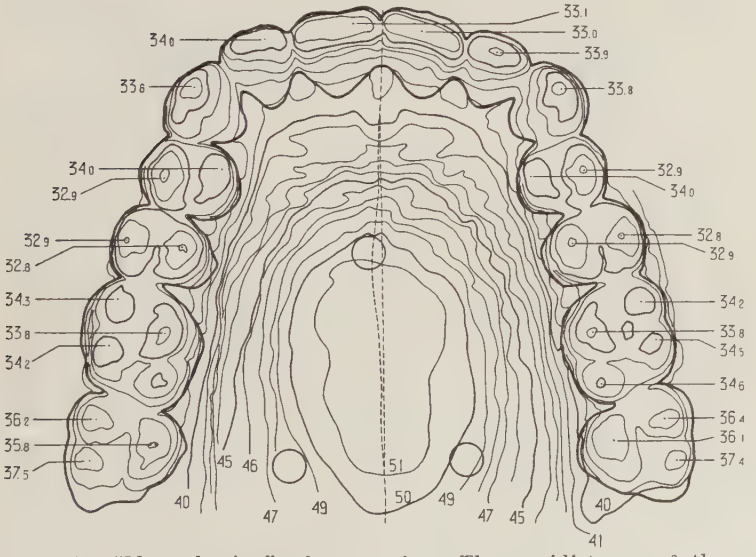


Fig. 13. "Map plotting" of upper jaw. The equidistance of the contour lines is 1 mm.

place followed by a displacement, which visibly affected the result of measurement.

A further weakness was that only impressions in the centre of the biting plate could be measured. The laboratory tests moreover took a long time and necessitated numerous tables and calculations.

In order to overcome these drawbacks, the following requirements must be fulfilled:

1) The biting planes must be of such small dimensions that only one rotation of the jaw joint can occur.
2) The biting planes must be of such a shape that every impression can be measured.
3) The composition of the biting planes must make occlusive biting possible, without interference of metal plates or steel pellets.
4) The shape of the biting planes must conform to the shape of the teeth, i. e. the material must mould itself to the anatomical shape and extension of the teeth.
5) The impressions must be measurable and possible to calculate by a mathematical formula.

I therefore started with some tests of the availability of different metals. Copper was galvanically precipitated directly into moulds which had been made in the mouth, on the same principle as when making copper dies. The result was negative, as the biting planes became too thin and the metal too hard. The impressions were diffuse. The same negative result was obtained with cadmium.

Tests with castings of lead or lead-tin showed different hardness numbers in spite of the same routine having been followed for investing, burn out and casting.

The only possible method proved to be by stamping lead plates. These were made from rolled sheet lead in the following manner: — Plaster casts were made in dentocoll moulds. A negative mould of the mandible was modelled in sand in a trough, in the same way as in the making of

steel plates, and a cast was made of Spence metal (graphite and sulphur).

The stamped-out lead plates were placed on the finished Spence cast, and the trough was filled with rubber dice of various sizes. Pressing was carried out in an apparatus, in which the load was about 25 tons depending on the thickness of the lead plates. After pressing, the lead plates were examined and cleaned.

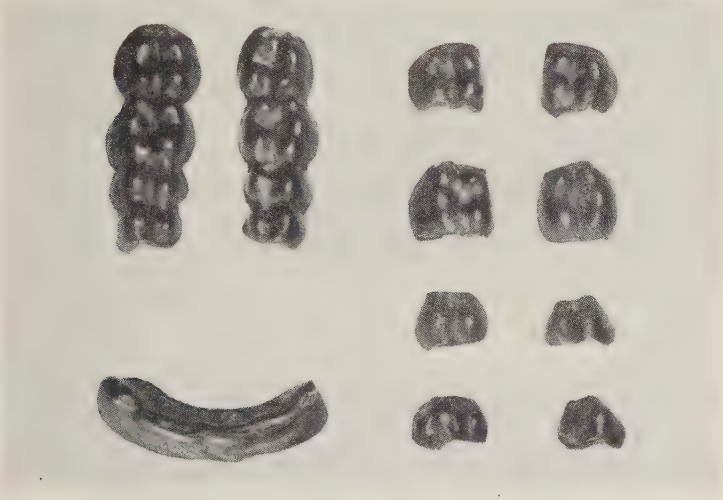


Fig. 14. Shaping of lead plates.

The same rolled plate was used for all tests. The exact thickness was measured by micrometer. Deformation, cracks, fractures or blisters were examined both macroscopically and microscopically, and the hardness was tested.

The biting planes were made in two thicknesses stamped out of lead plate of 0.5 mm. and 1 mm. (Fig. 14.)

The biting planes comprised both a block of premolars and molars, and were also stamped for individual teeth in the lower jaw.

Biting planes for full dentures were made in one piece from 7— to —7.

CHAPTER IV.

METHOD OF MEASURING

To determine the exerted force, when the cusps are pressed into the bite plane and leave permanent impressions, the following points have to be determined: a) the degree of hardness of lead, b) the curvature radii of the cusps and c) the shape of the surface of the impression.

In the previous chapter a description has been given of the tests carried out in order to find a metal suitable as the basic material in the investigation. The properties of the metal must be such that no damage would be caused to the teeth when their cusps pressed into the material. A further requirement was that the impressions caused by the exerted force should be possible to measure. Moreover, the material was required to be plastic so that an impression surface as similar as possible to that of the teeth should be obtained.

Experiments with copper, cadmium, tin-lead alloys and pure lead showed that only the latter answered all the requirements.

The hardness and elasticity of lead are slight, while its plasticity is considerable. On account of these characteristics lead has little resistance to permanent deformation, and thus lacks the ability to recover its original shape when the deforming force ceases. Its plastic capacity is on the contrary great, i. e. the capacity to keep the particles of the material together in spite of deformation.

The action of biting causes a deformation in the lead plates in those places where the cusps of the upper jaw teeth are pressed in, and impressions of various sizes are made according to the anatomical shape of the teeth.

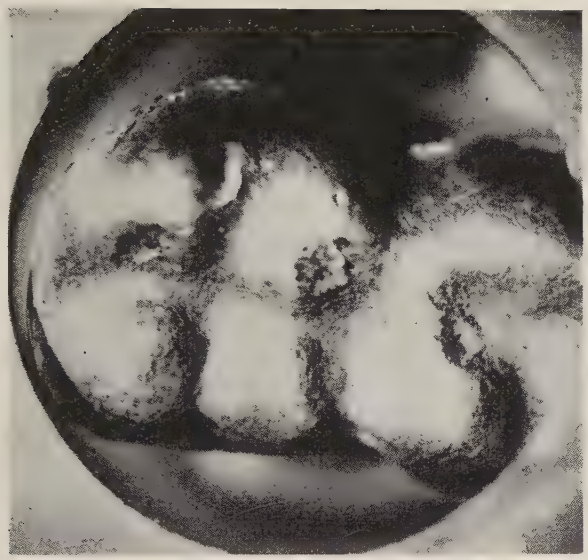


Fig. 15. Appearance of impressions (enlargement).

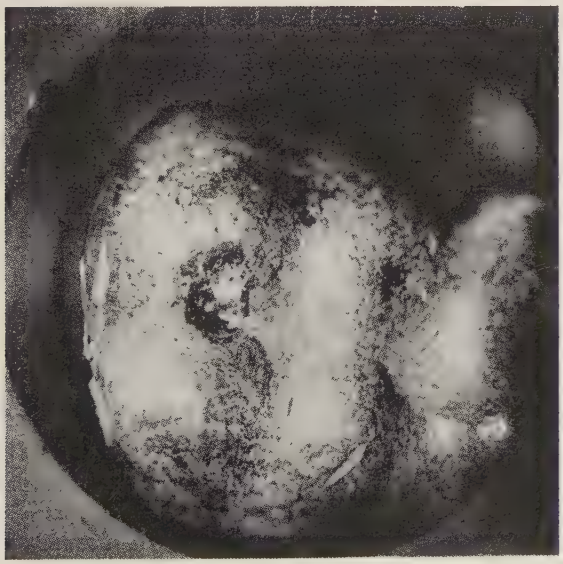


Fig. 16. Appearence of impressions (enlargement).

The deformation is both elastic and plastic, as has been pointed out above. The elastic deformation recedes immediately on completion of the pressure, while plastic deformation remains, as it is caused by the pressure having exceeded the elasticity limit. Fig. 15 and 16.

The determination of the degree of hardness of lead (the constant of force)

As the Brinell number of a material represents the limit of its elasticity and the point at which permanent deformation is caused, the knowledge of the degree of hardness of lead makes it possible to determine the force employed.

The Brinell test is carried out by means of a steel pellet of a given diameter being forced against the surface of a material with a given pressure.

The hardness is stated as being the pressure H_B on the contact surface between the pellet and the object, i. e. the quotient P/A of the pressure load P and the surface area A of the Brinell impression.

According to The Swedish Metallograph Society's handbook of hardness, published by Wretblad, the absolute surface area A_o of the Brinell impression is difficult to measure, and is therefore seldom used as a basis for determining the hardness number.

In its place either a spherical surface, approximately equal to A_o, is used, or the projection of A_o in the plane of the object surface, e. g. a circle area A_c.

The determination of the constant H in the expression $P = H \cdot A$ (P = force, A = projected surface of impression) was carried out by loading pellets of known diameters with known weights, whereafter the projected surface of the impressions obtained was measured by means of a microscope. The relation between the load and the projected surface was calculated, and this relation is equivalent to the required constant of force H.

In order to gain information of the constant of force (the number of hardness) H, its magnitude and value of

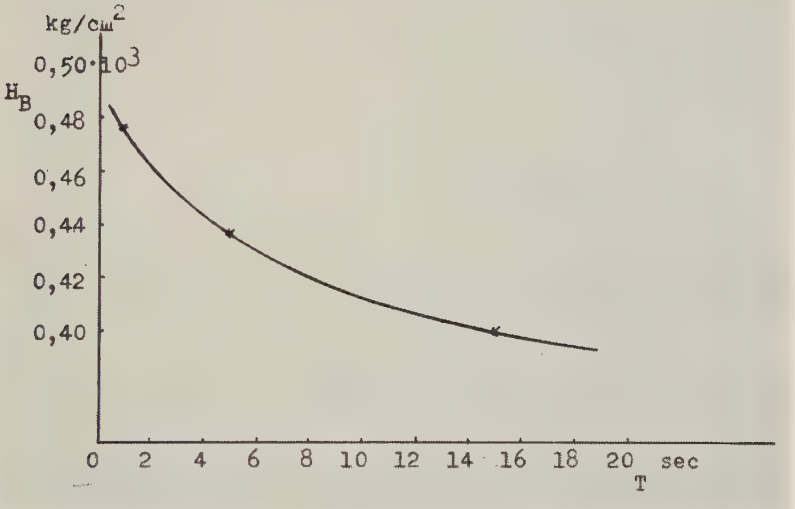


Diagram 1. Diagram of the hardness number of lead H_B, as a function of time T.

different loads, and varying diameters of the impression objects, a number of tests were made.

For a certain lead material which had been treated in the same way as the lead plates, which later were used in the intraoral tests, the constant of force was determined $H = \frac{P}{A}$ in an Alpha-Durometer-apparatus with a pellet of a diameter $D = 1.6$ mm. and a load of $P = 3$ kg. The time of loading was varied. The result is shown in diagram 1.

The time of loading has a decisive effect on the hardness number (constant of force).

When the desired load has been reached, the impression object must for a certain space of time press into the test material so that it can recede.

The constant of force of lead during different loading times has been tested by *Norbury* among others. He shows in the form of a diagram that $H_B/10/100$ is 4.5 in the original position, after 5 secs. 4.4 and after 1 min. 4.2,

further that $HB/10/50$ in the original position is 6.0, after 5 secs. 5.8 etc. These values are approximate, as it is difficult to determine the various points on the diagram (Handbook of hardness, page 81).

The author's own investigations confirm those of Norbury.

Time for biting in tests made both intra- and extraorally has in the following been limited to 2 secs. after contact has been established between cusps and bite planes. This is in order to avoid cooperation of the muscles of the neck, the floor of the mouth and the chin, which would distort the result. In determining the constant of force the time of loading has also been put at 2 secs.

With a hardness number obtained from this diagram a number of tests were made with determination intraorally of the force in biting. In this investigation the magnitude of the force per impression was calculated.

This force was obtained from the formula $P = H \cdot A$, where $A = \frac{\pi}{4} \cdot d_1 \cdot d_2$, i. e. the surface of the impressions was idealised as an ellipse, where d_1 and d_2 are the main diameters (see below).

Table 1. **The mean value of the force per impression in 10 normal cases.** Biting in group (molars and premolars).

Case no.	Force per impression kg. Plate thickness				Mean value
	0.5 mm		1 mm		
	right	left	right	left	
1	2.0	2.9	3.1	3.0	2.8
2	2.4	2.0	3.2	3.0	2.7
3	3.2	2.7	3.9	3.3	3.3
4	2.2	2.6	3.2	2.9	2.7
5	2.5	3.9	3.3	4.1	3.5
6	3.6	3.2	3.6	2.7	3.3
7	2.9	3.4	3.6	4.0	3.5
8	5.9	4.3	3.5	3.7	4.4
9	4.2	5.1	3.9	5.3	4.6
10	3.3	4.4	4.3	3.8	4.0
				Total mean value	3.5

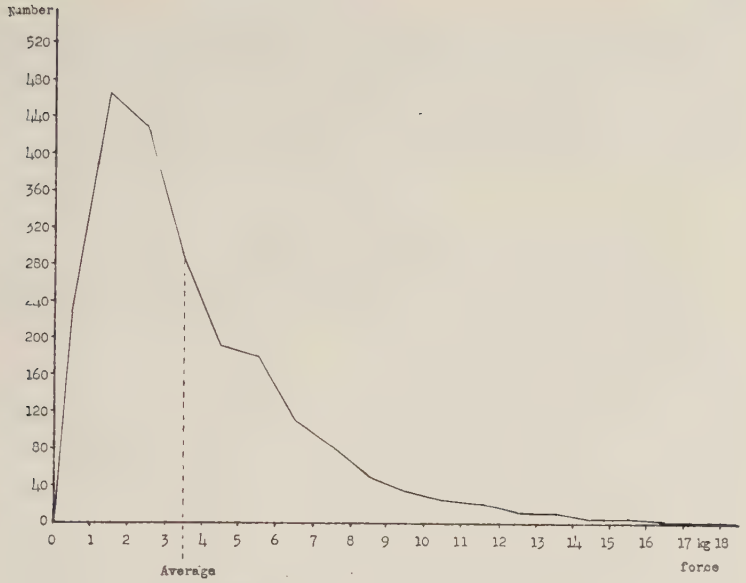


Diagram 2. The distribution of force per impression in 10 test cases. Biting in group (molars and premolars).

The mean value of this force was about 3.5 kg. when biting in group, which is illustrated by table 1 and 2 and diagram 2. From the diagram it is evident that most values are under the mean value and that only a small number are above 7.5 kg. Further it can be read from the diagram that the middle value is about 3 kg.

Table 2. **The distribution of force per impression in 10 normal cases.** Biting in group (molars and premolars)

kg	Number	kg	Number
0.0 – (1.0)	200	10.0 (11.0)	24
1.0—(2.0)	412	11.0—(12.0)	17
2.0—(3.0)	389	12.0—(13.0)	9
3.0—(4.0)	254	13.0—(14.0)	11
4.0—(5.0)	178	14.0—(15.0)	3
5.0—(6.0)	153	15.0—(16.0)	3
6.0—(7.0)	97	16.0—(17.0)	1
7.0—(8.0)	72	17.0—(18.0)	0
8.0—(9.0)	44	18.0—(19.0)	1
9.0—(10.0)	29		

On the basis of this examination a number of loads from 1 to 10 kg. were chosen for the final determination of the constant of force *H*. The pellet diameters were chosen with regard to the curvature radii of the cusps.

The curvature radii of the cusps

Curvature radii of the cusps of the teeth are obtained through profile projector measurements of vertically cross-cut cusps of plaster casts.

The radii are measured in the section which stretches from the highest point of the cusp along the ridge running against the central fissure of the tooth. This direction is neither bucco-palatine nor mesio-distal, but more towards the centre of the teeth. This section is most suitable for measurement, as its radius can be considered equivalent to the mean value of the radii obtained when the sections are measured in the bucco-palatinal and mesio-distal directions.

The cusps are numbered, and the results obtained are tabulated.

The mean value in each individual case was calculated, and from these 10 mean values a common mean value was determined, which was 1.07 mm. (Tables 3 and 4, and diagram 3). The diagram shows that there is an even distribution around the mean value, i.e. there is an equal number of values below and above.

Table 3. **Mean value of the curvature radius in 10 normal cases.** (Molars and premolars).

Case number	Curvature radii	Case number	Curvature radii
1	1.32	6	1.22
2	0.91	7	1.01
3	0.95	8	1.00
4	1.22	9	0.86
5	0.99	10	1.18
		Total mean value	1.07 mm

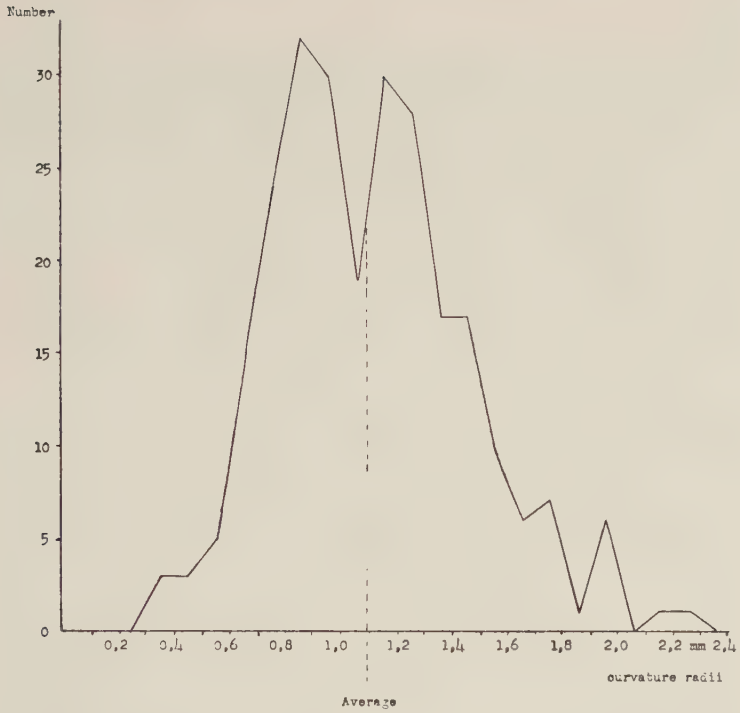


Diagram 3. The distribution of curvature radii in areas of various sizes according to Table 4.

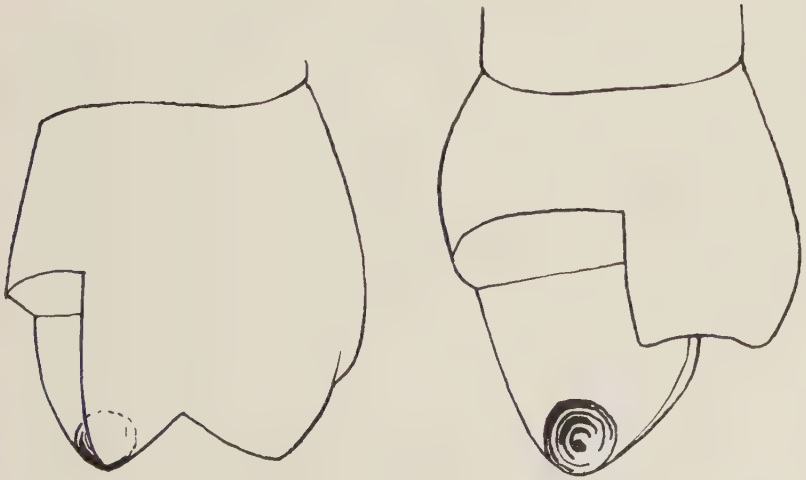


Fig. 17. Schematical picture of the method employed to determine the curvature radii of the cusps.

Table 4. **Distribution of curvature radii.**

mm	Number	mm	Number
0.30—(0 40)	2	1.30—(1.40)	13
0.40—(0.50)	2	1.40—(1.50)	16
0.50—(0.60)	5	1.50—(1.60)	4
0.60—(0.70)	13	1.60—(1.70)	5
0.70—(0.80)	21	1.70—(1.80)	3
0.80—(0.90)	27	1.80—(1.90)	1
0.90—(1.00)	26	1.90—(2.00)	3
1.00—(1.10)	14	2.00—(2.10)	0
1.10—(1.20)	24	2.10—(2.20)	1
1.20—(1.30)	21		

On the basis of this investigation a number of pellets were selected with diameters from 1.0 to 5.0 mm.

A series of tests was now made of H on different lead materials.

Test I: With an Alpha-Durometer apparatus impressions were made on 1 mm. lead plate (material I) with varying diameters of the pellets and with different loads, as is more clearly shown in table 5, were the H-value calculated from the test values are found. (Diagram 4.)

Table 5. **The constant of force at different loads and pellet diameter aecording to test I.**

Pellet diameter mm	Constant of force kg/mm². Load kg					Mean value
	3	4	5	6	10	
1.6	5.9	6.3	6.1	6.4	6.5	6.2
2.5	—	5.4	4.9	5.4	6.3	5.5
3.2	—	—	4.9	5.1	5.0	5.0
4.8	—	—	—	4.4	4.8	4.6
5.0	—	—	—	4.5	4.9	4.7

As is shown, the constant of force decreases as the pellet diameter increases.

Test II: With a Vicker apparatus impressions were made in 3 mm. lead plate (material II). The result is shown in table 6. (Diagram 4.)

Table 6. **The constant of force at different loads and different diameters of the pellet according to test II.**

Diameter of the pellet mm	Constant of force kg/mm². Load kg							Mean value
	1.0	2.5	3.5	5.0	6.0	7.5	10.0	
1.6	7.1	6.2	6.0	5.5	5.8	5.4	6.5	6.0
2.5	4.5	4.8	5.5	5.0	5.2	5.4	5.3	5.1
3.2	3.4	4.4	4.6	4.8	4.6	4.6	4.8	4.5
5.0	2.3	3.7	3.6	4.1	4.2	4.1	4.2	3.7

Test III: This test was also carried out in a Vickers apparatus. Lead plates of 1 mm. thickness were used. The result is shown in table 7.

Table 7. **The constant of force at various loads and varying pellet diameter according to test III.** (H calculated on the projected surface $A = \frac{\pi}{4} \cdot d^2$, where d = the diameter of the impression).

Diameter of the pellet	Constant of force kg/mm². Load kg						Mean value
	1.0	2.5	3.5	5.0	6.0	7.5	
1.0	5.0	5.2	5.7	6.7	—	—	5.7
1.6	(3.1)	4.6	4.7	5.1	5.2	5.2	5.0
2.5	3.7	3.8	4.0	4.4	4.6	4.6	4.2
3.2	3.2	4.1	4.5	4.1	4.1	4.4	4.1
5.0	2.9	3.1	3.1	3.3	3.6	4.0	3.4

Diagram 4 shows the constant of force as a function of a pellet diameter (the curvature radius).

The constant of force decreases as the curvature radius increases. From the tests it is evident that the constant of force varies with the diameter of the impression object, the thickness of the lead plate and the magnitude of the load. Divergence of the values also occurs, which is most likely due to local unevennesses in the surface of the lead plate, local variations in the hardness of the lead, and a certain error in the measurement of the diameter of the impressions. It is obvious that the constant of force should be determined for each lead material that is used, if a

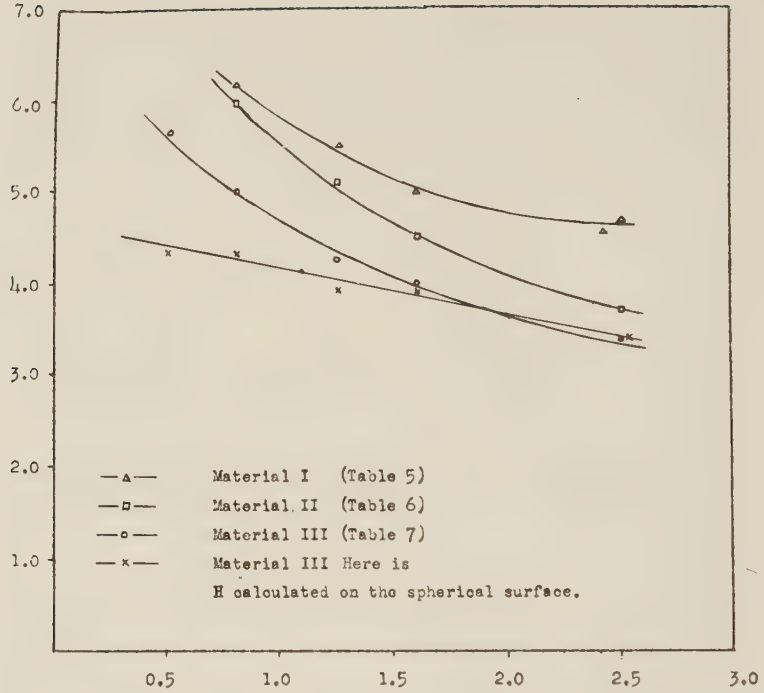


Diagram 4. The constant of force as a function of curvature radii in some different lead materials.

greater exactitude in the determination of the force is required, as well as for the curvature radius of the impression object (cusp).

In this test the constant of force has been calculated from the projected surface. In the case of an exact spherical impression object (as a pellet) the spherical surface is easily calculated, as is done in the Brinell tests, but when measuring the impressions of cusps in cases where the impression object is of a complicated shape, the size of the spherical surface is difficult to determine. The projected surface on the other hand is easily calculated, if it is idealized as an ellipse. Errors occurring in determining the force are eliminated, if a constant of force is used which is calculated from the projected surface. When a spherical

impression object is used, the calculation can be carried out either on the basis of the spherical surface or the projected surface, since the product of the spherical surface and *H* (calculated from the spherical surface) is equal to the product of the projected surface and *H* (calculated from the projected surface). In the case of a cusp, however, the spherical surface is of a less defined shape and therefore more difficult to determine with sufficient exactitude.

In certain cases conditions of loading may be such, owing to the anatomical shape of the teeth, that the lead has less chance of extending under pressure. This circumstance might affect the hardness of the lead, and to investigate this the following test was made.

Holes were drilled in a steel plate, and into the holes were fitted lead plates of the same thickness as those used in biting tests. On these lead plates hardness tests were carried out. The holes were of the same diameter as the pellet with which the hardness test was made. Because of its steel encasement the expansion capacity of the lead was reduced. There were *no* differences between the established hardness values and those obtained in these tests.

The shape of the surface of the impressions.

The shape of the projected surface of the impressions made by plastic deformation has been ideally described as an ellipse. The following test was made in order to gain information whether this simplification in description causes error in the calculation of the surface and consequently also in the calculation of the force developed.

Amalgam models were made of groups of bicuspids and molars in both sides of the upper jaw. Lead plates of 1 mm's thickness were treated according to the same principles as the bite planes.

These models served as impression objects in a Vickers apparatus and the load was between 2.5 kg. and 42.5 kg.

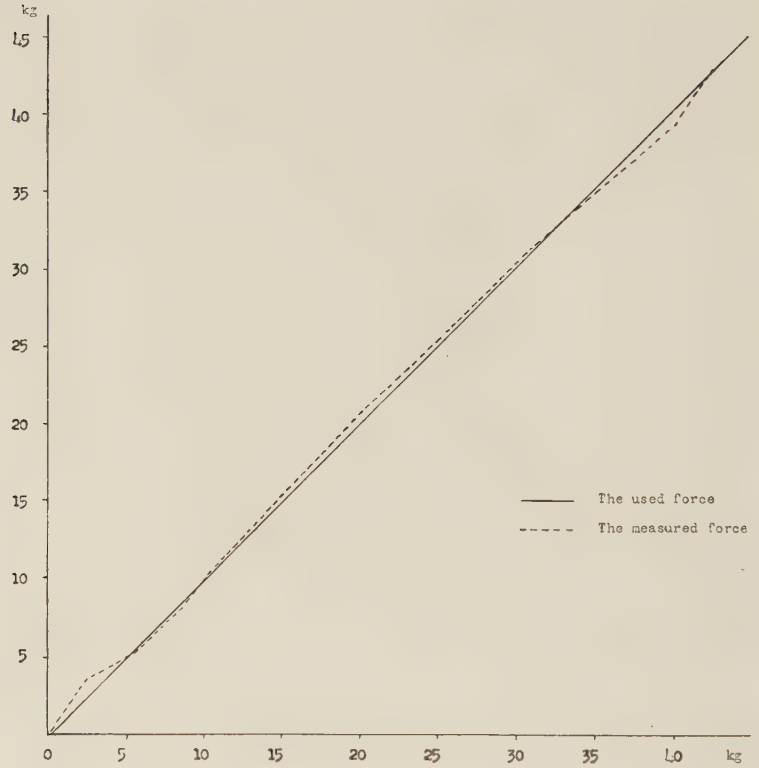


Diagram 5. Comparison between used and measured force in the loading of cusps. The force distributed on the cusps between second molar and first premolar. "The idealised ellipses."

The two impression diameters at right angles were measured in a microscope. The curvature radii of the cusps were measured in a profile projector, and the constant of force of the lead (hardness number) H was calculated.

From this diagram the value was obtained of the constant of force at the various cusps, and the force P was determined according to the formula

$$P = \frac{\pi}{4} \cdot d \cdot d_1 \cdot H$$

The investigation comprised 13 different loadings, and each loading included 2 to 6 tests. Altogether 58 tests were carried out. The inclination of the model in relation to the lead plate was varied, and individual cusps were also loaded in each test.

A comparison between the force used and measured is illustrated by Diagram 5.

From a comparison of the two curves it is evident, that no systematic error occurs, which is a proof that the method is reliable for the calculation of the developed force.

Determination of the force by measuring the depths of impression

The first apparatus for measuring the depth was constructed by Marten and Heyn, and was used by Schröder-Schönwald, as has been indicated in the historical survey. In their apparatus the force was registered at different depths in the course of the experiment.

Even Brinell however considered depth measuring to give unreliable hardness numbers, as the Brinell number obtained by depth measuring differs from that usually calculated on the basis of the diameter.

Depth measuring can give erroneous results, if unevennesses are observed in the surface of the object, and in order to obtain a depth value, the hardness number is determined from the difference between two or several loadings.

It is of interest to note that in the American regulations for Brinell tests, the use of depth measuring is not accepted as standard.

In this investigation the depths of the impressions have been observed by determining the curvature radii of the cusps, but attempts have also been made to measure the depth.

A number of impressions were measured with a Schmaltz's light ray microscope. Only the biggest and

deepest impressions were possible to measure, and the degree of exactitude was necessarily low on account of the position of the impressions on undulating surfaces. The same was the case when measuring with a Woxén surface indicator. The needle penetrated the material, and the registration only suggested, and did not mark with exactness, when the impression commenced and when it ended.

From the measurements, however, the information was gained that the depth of the impressions was on an average about the limit indicated by Wretblad as the point where the underlying material cannot influence the result.

The above shows the divergences which have been made from the standardised Brinell test, and a resumé follows below.

While Brinell uses a pellet which exercises a certain load, in the present method only the cusps of the teeth are used for producing a permanent deformation at biting.

In order to obtain an accurate Brinell number, it is necessary that the pellet is considerably harder than the material, so that no deformation of the pellet takes place. Its hardness is indicated as 1.7 times that of the impression material.

The hardness of the enamel shows that there is no risk of the cusps becoming flattened.

While the surface of the Brinell impression has a spherical form, the cusps produce another geometrical figure, which can ideally be described as an ellipse.

While Brinell calculates the spherical surface of the impression, the projected surface is used in this investigation, which gives the right physiological hardness number.

In the Brinell test the diameter of the pellet used is of standardised measurements, for instance 10.5 or 2.5 mm., and in any deviation the H_B is provided with an index showing the alterations made. In the present investigation the curvature radius of each cusp has had to be determined.

In order to investigate whether the anatomical shape of the teeth could affect the possibilities of the lead reced-

ing, a special test has been already described. This test showed that no change in the hardness number could be proved.

Meyer's relation

When a metal is worked on at a temperature sufficiently below its melting point (cold working), not only its structure but also certain physical and chemical qualities are altered. Hardness increases, i. e. a mechanical hardening occurs.

Bite planes used in measurements both in and ex ore are all cold hardened. They have been submitted to a pressure of 25 tons to be rendered perfectly suitable anatomically, and all lead plates have been treated according to the same norms and principles in order to obtain the desired finish.

The uniformity in the treatment of the lead gives each experiment the same starting point (under identical conditions), and thus makes each biting plane of the same hardness. Biting on the lead plates has lasted, with as great exactitude as possible, for 2 seconds after contact has been reached between the jaws. The resulting impressions are caused by plastic deformation.

In the Brinell test the relation between the load P in kg. and the impression diameter d is Meyer's relation

$$P = a \cdot d^n$$

where a and n are constants of the material. a conveys the load needed to produce an impression with a diameter $d = 1$ (when $d = 1$ equals $P = a$).

The constant n is a measure of the mechanical hardenability of the material. This is $= 2$ in the case of materials which cannot be mechanically hardened. The further n exceeds the value 2, the greater is the mechanical hardenability of the material.

The constant n has been fixed in the case of two of the

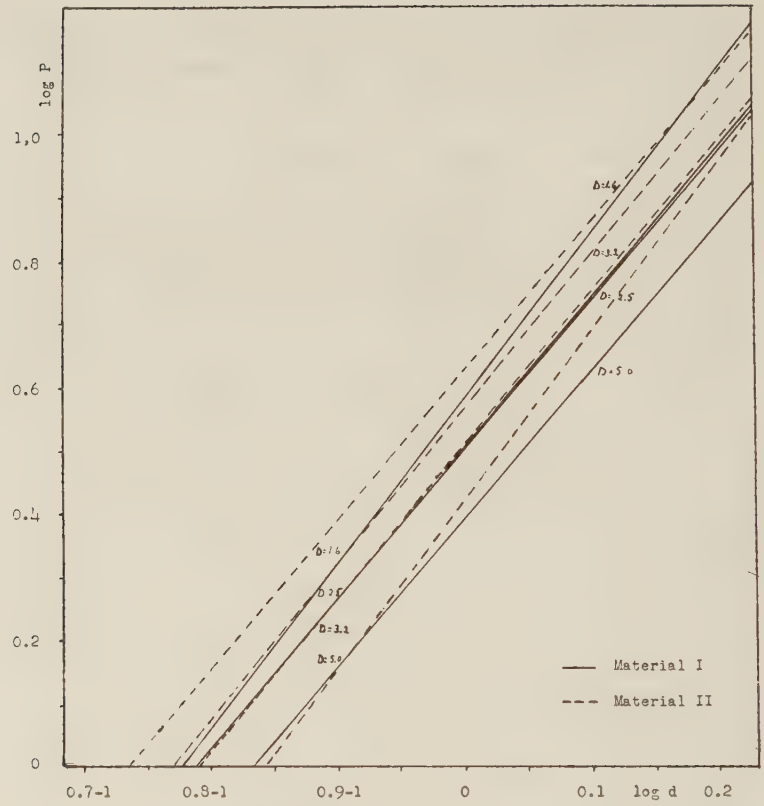


Diagram 6. Meyer's relation.

types of lead used in this investigation (the purity of the lead 99.85 %).

Meyer's relation has been transformed to logarithms, according to *Wretblad,* and thus becomes as follows:

$$\log P = \log a + n \cdot \log d$$

If this equation is graphically reproduced, a *straight line* is obtained, where n represents the inclination of the straight line.

As the mean value of n of material I (after four determinations with varying diameters D of the impression object) $n = 2.40$ was obtained, and for material II (accord-

ing to the same principles) $n = 2.44$. The diagram 6 shows P as a function of d, whereby n is determined.

These values show that lead can be mechanically hardened and that the hardness number increases in the course of biting. These figures do not however convey with certainty any information whether n, when equivalence is reached, is $= 2$, as the time of loading is too short.

By means of Diagram and Fig. 40 on page 96 of the handbook of hardness calculations, *Norbury* has graphically shown that the n value of lead, when equivalence is reached, is less than 2, but when the loading time is shorter, greater than 2.

This statement of Meyer's relation has only been included so as to determine the availability of lead.

The practical tests carried out in order to try the suitability of the method here presented, have clearly proved the availability of lead. As examples should be pointed out the tests of loading with known loads, which in the measurements have produced a P value of the same order.

Error of measuring

The error of measuring the force of mastication that is exerted by a single tooth was statistically established in the following way.*

All the impressions of two bite planes, right and left, 22 in all, were measured 14 times. The force of mastication by a single tooth is the sum of all impressions made by that tooth. The different impressions were combined for each tooth, the 22 deformations measured thus corresponding to 8 teeth: +7—+4 and 7+—4+.

The standard deviation of the series of 14 measurements of the force of mastication, thus comprising 1 –5 impressions, is given in table 8.

* The author is indebted to L. Goldberg, M. D. Pharmacological Dept., Karol. Inst. Stockholm, for valuable help with the statistical treatment of the material.

Table 8. **Establishment of the Error of Measuring the Force Exerted by a Single Tooth.** (Pb = 0 5 mm)

Tooth	Number of impressions	Average kg	Standard deviation (σ_x) kg	Error of Measurement (σ_m) $\sigma_m = \frac{1}{\sqrt{2}} \cdot \sigma_x$	
				kg	Per cent of average
+7	5	23.1	0.62	0.44	1.9 %
+6	3	9.5	0.43	0.30	3.1 %
+5	2	3.1	0.11	0.08	2.6 %
+4	1	1.5	0.14	0.10	6.7 %
+7 — +4	11	37.2	0.82	0.58	1.6 %
7+	3	16.5	0.66	0.47	2.8 %
6+	4	19.9	0.64	0.45	2.3 %
5+	2	4.7	0.21	0.15	3.2 %
4+	2	2.9	0.26	0.18	6.2 %
7+ — 4+	11	44.0	0.95	0.67	1.5 %

It is seen from the table, that the standard deviation $\sigma x)$ varies between 0.11 and 0.66 kg. for a single tooth, and 0.82—O.95 kg. for a bite plane.

As the final values were the mean of at least two single measurements, the error of measurement (σ_m) is

$$\sigma_m = \frac{1}{\sqrt{2}} \cdot \sigma_x$$

σ_x being the standard deviation of a single measurement.

It is clear from the table, that the error of measurement is comparatively slight, being 1.9—6.7 % of the average for a single tooth, and 1.5—1.6 % of the average for a bite plane.

CHAPTER V.

PRACTICAL APPLICATION OF THE METHOD OF MEASUREMENT

It is clear that a value found for a single tooth will vary when the experiment is repeated, due to experimental error of measure, different biting, variations in force exerted etc. The variability of force exerted by a single tooth from time to time was determined statistically as follows:

Variability of force

As the experiments were repeated a number of times, 3—5 times, the variability could be established by the method of double determinations. The difference between the values for the second and the third time were calculated, and the standard deviation of the difference (σ_d) calculated by ordinary formulae:

$$\sigma_d = \sqrt{\frac{(d - \bar{d})^2}{n - 1}}$$

where d = difference between 3rd and 2nd determination
$\bar{d}$ = mean difference
n = number of differences.

The result is seen in table 2, where the average of the determinations is tabulated in col. 3; the differences are tabulated in col. 4, and the standard deviation of the differences in cols. 5 and 6.

The mean differences between the single experiments were less than 2—3 times their standard error (col. 4)

and thus were not significant. This means that there is no systematic error to be found by biting from time to time, but the variations are due to random influences.

The variability of a single experiment (σ_e) is thus

$$\sigma_e = \frac{1}{\sqrt{2}} \cdot \sigma_d$$

and is tabulated in table 2, cols. 7 and 8.

It is obvious from the table that this variability is least for teeth 7 and 6 (15—38 %) and higher for the other teeth with their considerably lower average force (39—88 %).

It would not be unreasonable to assume that this variability from time to time is due to a number of factors, among others to a large variability in biting from time to time, as the error of measurement is slight or negligable (1.9—6.7 %) in comparison with the variability (see example).

Example: Variability (σ_e) = 40 %
Error of measurement = 7 %
Variability in biting = (σ_b)

$$\sigma_b = \sqrt{40^2 - 7^2} = \pm 39.4\ \%$$

This variability of a single value is rather large, but is of a magnitude often seen in biological work. As an example may be mentioned that the variability of the duration of local anaesthesia in teeth in man was 38 % on an average (Goldberg 1947); the method used had an error of 4 %.

As final value, used throughout this work for determining variability between individuals, the mean of at least 4 experiments was used. The variability of this final value (σ_m) was

$$\sigma_m = \frac{1}{\sqrt{4}} \cdot \sigma_e$$

Table 9. **Determination of the Variability of Force.**

Tooth	Number of cases	Average force kg	Mean difference ($\bar{d}$) $\bar{d} \pm \varepsilon_{\bar{d}}$ kg (3rd—2nd determination)	Standard dev. of diff (σ_d)		Variability of a single exp. (σ_e) $\sigma_e = \frac{1}{\sqrt{2}} \cdot \sigma_d$		Variability of final value (σ_m) $\sigma_m = \frac{1}{\sqrt{4}} \cdot \sigma_e$	
				kg	Per cent of average force	kg	Per cent of average force	kg	Per cent of average force
1	2	3	4	5	6	7	8	9	10
7+	10	18.30	—0.28 ± 1.05	3.31	18.09	2.34	12.79	1.17	6.40
6+	10	12.13	—1.23 ± 1.46	4.61	38.00	3.26	26.87	1.63	13.44
5+	10	3.07	0.25 ± 0.55	1.73	56.35	1.22	39.84	0.61	19.92
4+	5	2.45	0.42 ± 0.56	1.26	51.43	0.89	36.36	0.45	18.18
+7	10	19.25	—0.89 ± 0.92	2.91	15.10	2.05	10.70	1.03	5.35
+6	10	13.58	0.59 ± 0.90	2.77	20.40	1.96	14.42	0.98	7.21
+5	10	3.10	0 ± 0.39	1.23	39.68	8.90	28.05	4.45	14.03
+4	8	2.71	0.68 ± 0.85	2.40	88.56	1.70	62.61	0.85	31.31

This variability is tabulated in cols. 9 and 10, and is seen to vary between 5.4 and 13.4 % for teeth 7 and 6, and between 14.0 and 31.3 % for teeth 5 and 4.

The practical application of the method of measurement.

The practical application of the method of measurement was carried out in the following manner.

The patient to be tested was placed in a dental chair with head resting in such a position that the Camper plane, i. e. the plane which transverses porion acusticus and nasospinale, was congruent with the horisontal plane. This position is recommended by *Hildebrand* and *Lindblom* among others.

The biting planes were placed on their respective teeth and the patient was instructed to close the lips, bite firmly and swallow, and reopen the mouth. Time for biting was 2 secs. Only one bite was made on each plate.

During swallowing a check was made to confirm that neck and throat muscles were not employed. The secretion of saliva was also examined to see that is was normal. If a sliding movement was observed, the test was rejected.

The planes were placed on the right and the left side simultaneausly for each bite. Biting on one side only was not carried out. Only one bite was made on each bite plane. Each test was repeated at least 3 times. The results of these tests have been used as a basis for the statistical work on this subject.

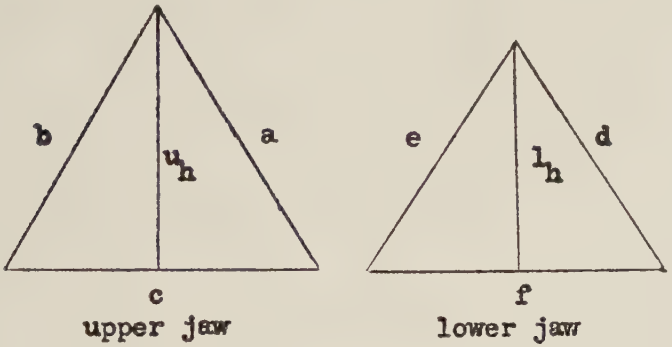
Investigation of 10 test cases

As test cases were chosen young people of 15 and above, with bite intact as far as the second molar or with very low frequency of caries, and in whom dental restoration only touched the fissures and the cusps were not cut down. This group of cases presented a normal bite of Angle class I. No polished facets or abrasions were to be found.

The group was selected so as to provide the greatest possible similarity in the relation between the jaws.

The jaws were measured according to the method indicated by the author in his "Practical application of stereometric measurement", i. e. triangles were inscribed between the incisal cross and the highest points of the disto-buccal cusps of the 7's in both upper and lower jaws.

The following Table illustrates the relation between sides, bases and heights, as well as the mean value. The relation between the height in the upper jaw and the height in the lower jaw is about 1.1 : 1 within a few per cent.



The relation between sides, bases and heights, and the mean value in 10 test cases.

Case	a:d	b:e	c:f	uh	lh	uh : lh
1	1.08	1.08	1.15	42.8	40.5	1.06
2	1.15	1.24	1.08	45.7	36.5	1.25
3	1.08	1.08	1.10	42.5	39.5	1.07
4	1.02	1.02	1.11	45.5	40.0	1.14
5	1.10	1.10	1.07	46.5	42.5	1.09
6	1.13	1.13	1.10	42.5	37.0	1.15
7	1.04	1.04	1.09	44.5	44.0	1.11
8	1.11	1.11	1.10	42.5	38.0	1.12
9	1.08	1.08	1.12	42.0	39.5	1.06
10	1.08	1.08	1.09	47.5	44.0	1.08
Average:	1.10	1.10	1.09	44.5	39.5	1.13

All curvature radii were measured in the profile projector, the hardness number of the lead was determined, and the force P was calculated.

The result of the investigation is shown in the following Table 10.

a) *Occlusive biting in group*

Table 10. **Occlusive biting in group.** Pb = 1.0 mm. (n = 10)

Tooth	Mean value $\pm$ ε_M	Stand. dev. kg	Range
1	2	3	4
7—	17.60 $\pm$ 1.60	5.06	10.93 — 26.64
6—	9.02 $\pm$ 1.21	3.82	4.09 — 17.13
5—	3.53 $\pm$ 0.60	1.71	1.30 — 6.03
4—	3.08 $\pm$ 0.50	1.58	0.93 — 4.99
—7	19.51 $\pm$ 1.40	4.42	10.61 — 24.28
—6	8.41 $\pm$ 1.80	5.70	3.45 — 21.03
—5	2.37 $\pm$ 0.39	1.18	0.86 — 4.33
—4	2.72 $\pm$ 0.26	0.79	1.41 — 4.06
7— — 4—	32.5 $\pm$ 1.79	5.65	24.84 — 43.03
—7 — —4	32.5 $\pm$ 1.85	5.87	24.37 — 46.15
7— — —7	65.03 $\pm$ 3.15	9.99	55.44 — 89.45

The total force developed between the jaws is according to the above Table 65.03 $\pm$ 3.15 kg., and the force is evenly distributed on the right and left side. No systematic difference is found. The difference which may occur in a single case is due to the variability of the force, the anatomical shape of the teeth, their relation to their antagonists, as well as to the manner of biting.

The distribution of the force on the right and the left side at the various teeth is also shown in the Table. The greatest force is developed at the second molar, 17.6 kg. on the right and 19.5 kg. on the left side. At the first molar hardly more than half that force is registered, 9 kg. on the right and 8.4 kg. on the left. At the two bicuspids the values of the force drop very markedly. Thus the value at the second bicuspid is on the right side 3.5 kg. and on the left 2.4 kg. At the first bicuspid the figures are 3 and 2.7 kg.

The max. variation at the various teeth and groups is shown in col. 4. The lowest and highest values at the second molar are 10.9 kg. and 26.6 kg., at the first molar 3.5 kg. and 21 kg., at the second bicuspid 0.9 and 6.0 kg., and at the first bicuspid 0.9 and 5 kg.

The mean value of the force developed from 7 to 4 is 32.5 kg. ± 1.8, with the lowest value 24.4 and the highest 46.2 kg.

The mean value of the total force from 7 to 7 is 65 kg., with a variation from 55.4 to 89.5 kg.

When biting was carried out on bite planes of 0.5 mm. thickness, the results were of the same magnitude. *No significant difference was found between the values obtained in biting tests on planes of these thicknesses.*

The result duly proves the correctness of the assumption that bite planes of these dimensions do not exceed physiological limits, i. e. they have no diverting effect on the physiological course of movement of either the jaw joint or the mandible.

b) *Occlusive biting by single teeth*

Table 11. **Occlusive biting by single teeth.** Pb = 1.0 mm. (n = 10)

Tooth	Mean ± ε_M	Stand. dev. kg.	Range
7—	32.79 ± 1.75	5.53	22.7 — 43.4
6—	29.55 ± 2.93	9.27	14.1 — 45.9
5—	24.36 ± 1.96	6.19	14.7 — 38.7
4—	25.73 ± 1.67	5.29	15.5 — 32.9
—7	33.84 ± 2.91	9.17	22.0 — 52.6
—6	28.23 ± 1.51	4.78	22.3 — 36.6
—5	25.73 ± 2.20	6.96	17.5 — 40.1
—4	22.58 ± 1.88	5.95	15.4 — 35.5

From an odontological point of view it is of interest to note the distribution of force of the different teeth in relation to the total force. From the above measurements it is quite evident that there is no even distribution or distribution with even intervals. It is also of interest that

the greatest force is found at the second molar, while at the first molar hardly more than half that force has been measured.

As a comparison is given below a table of occlusive biting by single teeth, when a bite plane of 0.5 mm. thickness has been used.

Table 12. Pb = 0.5 mm. (n = 10)

Tooth	Mean $\pm \varepsilon_M$	Stand. dev. in kg.	Range
7—	33.10 ± 2.13	6.74	24.3 — 45.7
6—	26.73 ± 2.22	7.03	14.7 — 40.3
5—	23.71 ± 1.99	6.31	13.4 — 36.9
4—	21.24 ± 1.54	4.86	13.2 — 26.9
—7	34.27 ± 3.20	10.1	16.8 — 51.5
—6	24.96 ± 1.72	5.42	17.4 — 32.4
—5	24.00 ± 2.15	6.80	16.1 — 35.7
—4	19.08 ± 1.65	5.21	9.3 — 26.3

Below are tables 13 and 14 showing the total force developed on right and left side. Results obtained with bite planes of 1.0 and 0.5 mm.

Table 13. Pb = 1.0 mm. (n = 10)

Tooth	Number	Mean $\pm \varepsilon_M$	Stand. dev.	Range
7— — —7	10	66.63 ± 3.66	11.57	54.5 — 96.0
6 — — —6	10	57.78 ± 3.59	11.36	47.4 — 79.5
5— — —5	10	50 09 ± 3.39	10.72	37.5 — 67.9
4— — —4	10	47.59 ± 2.92	9.22	34.5 — 68.4

Table 14. Pb = 0.5 mm. (n = 10)

Tooth	Number	Mean $\pm \varepsilon_M$	Stand. dev.	Range
7— — —7	10	67.37 ± 4.66	14.73	44.7 — 97.2
6 — — —6	10	51.73 ± 2.58	8.16	41.4 — 69.6
5 — — —5	10	47.71 ± 3.35	10.58	29.8 — 59.4
4 — — —4	10	40.32 ± 1.86	5.89	29.5 — 47.3

The Tables show, that the total force developed between the jaws is 66 kg., and it is evenly distributed on the right and the left side. No systematic difference is found. The difference found in some individual cases is caused by the variability of the force, the differences in the anatomical shape of the teeth and their relation to their antagonists, as well as by the manner of biting. The greatest force is developed at the second molar and is 33 kg., at the first molar it is 29 kg., at the second bicuspid 25 kg. and at the first bicuspid approximately the same as at the second.

A comparison between the forces developed, when a bite plane stretching from 7 to 4 is used and when biting on a single tooth takes place, shows that the total force gives the same result in both cases, namely 65—66 kg. It is also of interest to note that the force diminishes towards the front and is least at the first bicuspid.

If the maximal variation at the single teeth and at different groups of teeth is compared, the figures also agree. In general all the statements hold good, which have been made in the presentation of results of occlusive biting in group.

Occlusive biting in group. 36 cases. Pb = 1.0 mm.

The suitability of the method was tested in chosen cases, where the only requirement was that the teeth should contact each other within the dental arch and intermaxillarily in occlusion. It was also of interest to obtain information of the force developed between jaws of varying sizes, varying forms, on varying numbers of teeth with and without fillings. The test material consisted of students of both sexes in the ages of 22—28 years.

The results are given in the following Table 15.

Generally the statement holds good, that the developed force is distributed in the same way as in the 10 Test Cases, only the values are lower throughout. Thus the force measured at 7— is 13.2 kg. and at —7 13.1, at 6—

Table 15. **Occlusive biting in group.** Pb. = 1.0 mm. (n = 36)

Tooth	Mean value ± ε_M	Stand. dev. in kg	Range
1	2	3	4
7—	13.23 ± 1.44	8.66	3.39 — 35.27
6—	6.23 ± 0.89	5.31	0.51 — 20.01
5—	3.05 ± 0.39	2.19	0.61 — 10.39
4—	3.51 ± 0.65	3.54	0.36 — 13.28
—7	13.08 ± 1.42	8.49	2.55 — 33.58
—6	6.76 ± 0.76	4.56	0.72 — 16.61
—5	2.94 ± 0.36	2.09	0.28 — 10.35
—4	3.34 ± 0.46	2.52	0.38 — 11.26
7— —4—	24.44 ± 2.30	13.8	5.72 — 66.29
—7 — —4	25.30 ± 2.13	12.8	2.48 — 48.79
7— — —7	50.02 ± 3.88	23.3	8.20 — 100.89

6.2 kg. and at —6 6.8 kg., at 5— 3.1 kg. and at —5 2.9 kg., and finally at 4— 3.5 kg. and at —4 3.3 kg. The combined force on the right bite plane is 24.4 kg., on the left 25.3, and the total force 50 kg. Lowest and highest values are at 7— 3.4 kg. and 35.3 kg., at —7 2.6 and 33.6 kg., at 6— 0.5 to 10.4 kg., at —6 0.7 kg. to 11.6 kg., at 5— 0.6 kg. to 10.4 kg., at —5 0.5 kg. to 10.4 kg., and finally at 4— and —4 0.4 to 13.3 and 0.4 to 11.3 kg. On the right bite plane 5.7 to 66.3 kg., on the left 2.5 to 48.8 kg., and the mean value of the total force is 8.2 and 100.9 kg.

Discussion

It was pointed out in the statement of the total force that the latter was evenly distributed on both sides, and that the difference, which can be seen between the two sides, arises from the variability of the force, differences in the jaws as well as the anatomical shape and position of the teeth in relation to their antagonists, and finally from the adaptability of the mandibular joint and the muscles to the bite. This can also be defined thus, that the bite balances its function with regard to the above factors. According to *Wikblad,* the balance of the bite is

conditioned on one side by the size and distribution of the load, and on the other by the paradental tolerance and capacity.

Hanau and *Thielemann* have introduced the term articulation equilibrium instead of balance.

The former has grouped in a "quint" the five factors which are mutually dependent for the reaching of this equilibrium, and the latter has combined these articulation factors in a formula.

Thourén denies that there is any natural connection between these factors in a present day bite. The formula is useful only in the construction of a complete prothesis. He points out that in the adult bite, which develops under great demands on its function, articulation is neutralised by the muscular work and the abrasion, which outweighs the movements of the mandible in relation to every kind of necessary masticatory force and compensates the atrophies connected with ageing.

In this connection the conception can also be discussed that the mechanics of the jaw movements are wholly dependent on the inclination of the condyle path. Many authors use this axiom to support their investigations. *Thielemann* holds the view that the condyle path is the most important factor in the movement of the mandible.

Experience shows, that a double sided total extirpation of the condyle does not prevent movement or mastication to any great extent. One-sided extirpation, however, causes a contraction upwards of the operated side at the opening movement, but at closing the mandible is again brought back into occlusion *(Wikblad)*.

This observation shows that the mandibular joint does not work in the same way as for instance the knee joint. The mandibular joint can be best described as a pivot with the task of guiding the mandible into the position where the cusps of the teeth take over the task of guiding into central occlusion, and also to prevent "derailing" through excentric movements or traumata.

The factor regulating its movements at biting and chewing must undoubtedly be said to be the muscles whereby the mandible is suspended. Direction and force depend on the position of these muscles in relation to each other, and are reflected in the resultant of force obtained through a combination of the components of force of the different muscles.

This regulative factor is dependent on the position and number of the teeth in both halves of the jaw, and extractions on one side or abnormal positions show that the force developed becomes unevenly distributed.

If a displacement of the mandible has taken place towards either side, owing to wrong bridge-construction or early extractions, the mandible can be brought back to its original position by means of bite splints and effective prothesis. At the same time the muscles regain their natural regulative task. The change in the condyle's position in relation to tuberculum articulare has been rectified by the treatment. It is difficult to give an X-ray analysis of a normal position or path of a condyle. Most likely each individual has a certain normal position and normal path, and this is probably not fixed to a single point, but there is undoubtedly quite a considerable tolerance.

That the mandible in the adult bite should be considered a one-armed lever, where force and distance from the fulcrum should be invertedly proportional, can certainly be questioned. The result of this investigation shows that no definite intervals between the values at the different teeth are obtained which might prove conformity to the lever laws. On the contrary, the force by biting has proved to be independent of the anatomical relation between teeth and jaws. An even distribution of the force on the right and left sides has been a sign that the regulative muscle force caused a balance between the two sides, which from a purely anatomical point of view have often shown great differences. There is no great probability that such a balance could take place through the inclination of the

condyle path and the following of this path by the mandible.

In the case of constructing a complete prothesis the problem is different and will be discussed in the following chapter.

Measurement of the force by biting in cases of periodontal disease and in cases of complete denture cases

In determining the force developed, a constant of force, a hardness number, must be used, which corresponds in each individual case with the curvature radius of the cusp and with the time of loading.

The biting time has been limited to 2 seconds. Considering the difficulty in judging the exact length of time needed for closing the mouth, biting and reopening the mouth, a miscalculation may occur.

The curvature radii for all cusps have been tabulated, and from these a mean value of all the 46 cases has been calculated. The radius is about 1 mm., with a divergence of 0.8 to 1.5 mm.

If a hardness number is used corresponding to the mean value of the curvature radii, an error naturally occurs, as the curve on the *H*-diagram is not a straight line but becomes steeper for smaller curvature radii, i. e. cusps with a radius below the mean value would be underestimated.

An investigation of 10 test cases showed however that the distribution of curvature radii around the mean value is even, i. e. there are as many values below as above the mean value. (Diag. 3.)

If a common constant of force is used in each individual case of the 10 test cases, the error is found to be as shown in the following Table 16.

If in a series of investigations a common *H*-value is used, based on the mean value of the curvature radius for the whole series of tests, a considerable error may arise in certain individual cases. To the above mentioned error

Table 16. **Errors in the H-value when the same constant is used.**

Case no.	Constant H kg/sq. mm			% Error		
	Mean	Mean value lower half	Mean value upper half	Lower half	Upper half	Mean error
1	2	3	4	5	6	7
1	4.20	4.45	4.00	— 5.6	+ 5.0	— 0.3
2	4.80	5.15	4.50	— 6.8	+ 6.3	— 0.3
3	4.70	5.05	4.40	— 6.9	+ 6.8	— 0.1
4	4.30	4.70	4.10	— 9.3	+ 4.9	— 2.2
5	4.65	5.15	4.35	— 9.7	+ 6.9	— 1.4
6	4.30	4.60	4.15	— 7.0	+ 3.6	— 1.7
7	4.60	5.20	4.20	— 11.5	+ 9.5	— 1.0
8	4.65	5.15	4.35	— 9.7	+ 5.7	— 2.3
9	4.85	5.15	4.60	— 5.8	+ 5.4	— 0.2
10	4.35	4.75	4.15	— 8.4	+ 4.8	— 1.8

must be added the error occurring when the common *H*-value is used instead of the *H*-value of the particular case. The amount of this error in the present series of investigations is shown in a Table below.

Table 17 shows the error in determining the force in all 10 cases, when as constant *H* a common mean value (4.5 kg./sq.mm.) has been used instead of an individual value for each case:

Table 17.

Case no.	Curv. radius mean value mm	Correct constant H kg/sq. mm	Constant used H kg/sq. mm	Error %
1	1.32	4.20	4.50	+ 7.1
2	0.91	4.80	4.50	— 6.2
3	0.95	4.70	4.50	— 4.3
4	1.22	4.30	4.50	+ 4.7
5	0.99	4.65	4.50	— 3.2
6	1.22	4.30	4.50	+ 4.7
7	1.01	4.60	4.50	— 2.2
8	1.00	4.65	4.50	— 3.2
9	0.86	4.85	4.50	— 7.2
10	1.18	4.35	4.50	+ 3.4
Mean value	1.07	4.50		± 4.2

The above Table shows that, with a mean value $H = 4.5$ kg./sq. mm. of the constant, an error occurs in determining the force of the individual cases ranging from —7.2 % to +7.1 %, on an average an error of ± 4.2 %, with *no systematical deviation from the true value.*

These investigations show that a curvature radius of 1 mm. and a corresponding hardness number are justified in ordinary practice, where a certain margin may be allowed and where, for instance, the object is only to state whether a tooth can be used as support in a bridge construction or to define the functionability of one or several teeth. The diagram of the constants of force must always be constructed. To the values obtained should be added the error of about ± 5—10 %, which values are well within reasonable limits for odontological requirements.

According to these principles a measurement was carried out of the biting force in cases of complete prothesis and another in cases of periodontal disease. Each group comprised 10 cases. ($H = 0.475$ kg./sq.mm.)

Measurement of the biting force in cases of periodontal disease

The ten following cases were taken at random from a practice with ordinary patients, and were not selected. The aim of the tests has been to measure the biting force and to apply the method.

In all these cases there was severe marginal destruction of either horizontal or vertical type, or of both types combined, extending over half of the root or more both in the upper and lower jaws. The bites were more or less collapsed, and the single teeth showed a mobility of the 2nd or 3rd degree.

Method. Bite planes were stamped out for groups of molars and premolars, and also for incisives and canine teeth in the lower jaw. Only one thickness of lead plate, 0.5 mm., was used.

Case 1. Molars and premolars were missing. As the central incisives in the upper jaw were loose and fitted with porcelain crowns, incisive biting had to be carried out with great caution.

The measurements showed a force of 0.9 and 2.5 kg. at 1+, and 1.0 and 1.3 kg. at +1.

Case 2 presented the most pronounced area of disease in the lower jaw between 3— and —3. In the front the force was 8.5, 1.5 and 10.8 kg. at 2+. The figures obtained at +2 were 4.1, 1.7 and 6.9 kg. In occlusive group biting the values were (average of 3 measurements):

from 7— to 4—: 20.6 kg.
from —7 to —4: 8.0 kg.

Case 3 showed in incisive biting a maximum force of 2.0, 4.3 and 5.1 kg. at 1+, while the figures at +1 were 9.0, 10.0 and 10.5.

Case 4. In this case the marginal destruction covered as much as ⅔ of the root length. Incisive biting showed a force of 6.1 and 7.4 kg. at 1+, and at +1 the values were 6.3 and 3.4 kg.

Case 5. Especially pronounced marginal destruction was observed in the front regions of both jaws.

Results of measurements (average of 3 measurements):

2+ = 1.9 kg.
1+ = 1.2 kg.
+1 = 1.9 kg.
+2 = 2.7 kg.

Case 6. The patient complained about pains at the slightest biting and general tenderness in the jaws. Of three tests taken one was successful, and clear impressions were obtained of 2+ and +2, giving the figures 0.5 and 1.8 kg.

Case 7. This case showed slight destruction (horizontal type) throughout.

In occlusive group biting the force measured (average of 3 measurements):

from 8— to 4—: 6.8 kg.
from —8 to —4: 8.8 kg.

In incisive biting the results were 2.1 kg. at 1+, 1.2 kg. at +1 and 3.2 kg. at +2.

Case 8. In protrusive bite the figures obtained at 1+ were 2.7 and 2.6 kg., and at +1 19.1 and 16.4 kg.

Case 9. All incisives in the lower jaw were exposed almost to apex buccally and two thirds lingually, and were mobile to the 3rd degree, while the remaining teeth were mobile to the 2nd degree. Biting was carried out with the utmost caution. The force was 7.0 and 7.5 kg. at 1+, and 12.6 and 10.9 kg. at +1.

Case 10. In this case the destruction had not reached as far as in previous cases, yet from a clinical point of view all teeth in the front were loose to the 2nd degree. In protrusive bite only +1 made contact with the bite plane, and at this tooth the value 13.5 kg. (average of 3 measurements) was obtained.

Measurement of the force by biting in cases of complete denture cases

When measuring the force by biting in cases of complete denture cases bite planes of 0.5 mm. were used including all teeth from the second molar on the right side to the same molar on the other side of the jaw.

The reason why this type of bite plane was chosen was that the lower jaw denture can be considered a continuous unit, and that this bite plane prevented any variations in the position of the occlusive bite.

In order to determine the force by biting, tests were made with three bite planes for occlusive biting and three planes for edge to edge biting.

The results are presented in Table 18 and 19, page 73, where the average value of the force, its distribution, variability, as well as the range, are given.

In the construction of a complete denture the artificial teeth are chiselled so as to form as many contact points as possible, and in cases of protrusive biting (edge to edge) contacts are required between the incisives in the upper and lower jaws as well as from the first molar and backwards. This is in contrast to normal cases, where in protrusion contact is lacking on the molars.

Adjustment of articulation is necessary in the construction of a complete denture, i. e. the geometrical factors of articulation, incisal inclination and the inclination of the occlusion plane, the curve of the occlusion plane and the inclination of the cusps, which are all four variable, must be adapted to the fifth factor, the inclination of the condyle, while at the same time filling the requirements of the static rules to prevent tipping and shearing action.

Tipping action does not occur, if the masticatory force falls within the vestibular edge of the prothesis, and shearing is prevented by keeping the cusps flat and the occlusion surface parallel with that of the antagonists.

The following results were found: —

In occlusive biting impressions were seen only in the region of the second molar as far as the first bicuspid. The force is evenly distributed on both sides, and the average value of the total force is 20.4 kg. The lowest and highest values are 7.1 and 36.8 kg.

In occlusive biting with complete prothesis only 31 % of the force exerted in normal cases was developed by $n = 10$, and by $n = 36$ cases 40 %. The difference is significant.

In protrusive biting impressions are obtained partly of the front teeth and partly of the molar regions of both sides. The force is equally distributed in all three regions, the average value of the total force being 22.7 kg. The lowest and highest values are 9.1 and 50.1 kg.

A clinical examination of the ten cases of complete dentures was made before the tests in order to ascertain whether constructional defects had any effect on the force of mastication.

Case 1 and 3 were impaired by constructional defects. The force exerted in these cases in occlusive biting was only a third of the average of the total force in cases with complete dentures.

In cases 2, 4 and 10 there were smaller constructional defects, and especially the chiselling of the cusps was unsatisfactory. None of these reached the average value of the total force of the ten cases with complete dentures.

The remaining cases were altogether correctly made, and especially cases 6 and 7 were carefully constructed and chiselled. The values obtained were considerably above the average value, being 28.7 and 36.8 kg.

In protrusive biting the same relation was observed between the force and the construction.

(n = 10)

Tooth	Number	Mean $\pm \varepsilon_M$ kg	Standard deviation kg	Range
1	2	3	4	5
7— —4—	10	10.0 ± 1.6	5.2	3.1 — 18.2
—4— —7	10	10.5 ± 1.6	5.0	3.3 — 18.7
Total	10	20.4 ± 3.2	9.9	7.1 — 36.8

Table 18. Occlusive biting by complete prothesis. Biteplane 0.5 mm.

(n = 10)

Tooth	Number	Mean $\pm \varepsilon_M$ kg	Standard deviation kg	Range
1	2	3	4	5
3— — —3	10	6.9 ± 1.0	3.1	3.2 — 13.8
7— —4—	10	6.9 ± 1.7	5.4	1.8 — 18.1
—4— —7	10	8.1 ± 2.0	6.2	1.2 — 18.2
Total	10	22.7 ± 3.9	12.3	9.1 — 50.1

Table 19. Protrusive biting by complete prothesis. Biteplane 0.5 mm.

CHAPTER VI.

COMPARISON BETWEEN EARLIER INTRAORAL MEASUREMENTS AND THE AUTHOR'S OWN MEASUREMENT

From the historical resumé (pages 8 -10) it is evident that in intraoral measurement of the force of occlusive biting — and not, as it has been erroneously called, the masticatory force, which is impossible to measure with present resources — four investigators, Schröder & Schönwald and Köhler & Etling, have in the Brinell test made use of steel pellets applied to steel rails or direct on the fissures of the teeth in the upper jaw. These pellets have in occlusive biting been pressed against plane metal plates of lead or "Reichszinn" placed on the teeth in the lower jaw (Fig. 4 and 5).

The author's apparatus consists only of stamped out lead plates (purity of lead 99.85 %), which mould themselves to the anatomical shape of the teeth (Fig. 14). The steel pellets are substituted by the cusps of the teeth.

The space between the jaws, when contact was made between bite plane and pellet or bite plane and cusps, in the tests made by Schröder & Schönwald was 10 to 20 mm., in tests by Köhler & Etling 6 to 10 mm., and in this investigation 0.5 to 1 mm.

The great distance of 6 to 20 mm. can with the utmost probability be said to exceed the limits of the free way space, which on an average is estimated to 3 to 5 mm. The free way is defined as the space between the physiological resting position and the tooth contact position in a centric occlusion.

This great distance influences the shape of the impression owing to the fact that the occlusion does not take place vertically through the movements of the mandibular joint, which become a combined rotating and gliding movement, and thus an error occurs in the measurement and calculation of the force.

K ö h l e r & E t l i n g also point out that only the impressions in the centre of the plate are measurable.

In the present investigation the bite plane is within the limits of the free way space, with a broad safety margin. All impressions are measurable.

Another fundamental difference in measurement is that previous authors have only measured one side of the jaws, while in this investigation measurements have been carried out simultaneously on the right and the left side.

The reasons for doing so have been explained in Chapter II, physiological conditions.

A further difference of the greatest importance is that the cusps of the teeth make the impressions instead of the steel pellets. The advantage of a fixed and firm impression object should not require to be discussed.

The substitution of the steel pellets by cusps has brought out a new shape of impressions. The projected surface of the impression shape has been ideally described as an ellipse. In order to gain a conception of whether this simplification causes error in the calculation of the surface, and consequently also in the calculation of the exerted force, a series of tests have been made. These tests comprise a comparison between surfaces of known and measured force (page 47, Diagram 5). The result has proved that the idealised geometrical figure is fully applicable.

The published test material of S c h r ö d e r & S c h ö n w a l d comprises only one case, a youth of 16, where occlusive bite was measured with 10 mm. between the jaws in regio molaris I, a force of 39.125 kg. being

exerted, with 12.8 mm. 36.6 kg., with 15.25 mm. 23.125 kg., with 17.25 mm. 17.5 kg. and finally with 20 mm. 12 kg.

Köhler & Etling have published 10 cases. Of the ten cases described No. 4 is the most interesting, dealing with a young man of 18 without caries and with normal bite. Unfortunately only the right side was measured.

In this case steel pellets were applied, with bite planes on the antagonists. (Time for biting 3 –5 seconds.) The distance between the jaws varied from 6 to 12 mm. The force measured at 7 was 55 kg., at 6 60 kg., at 5 37 kg., and at 4 30 kg. At the incisives the force varied between 24 and 26 kg.

In another case, where all teeth in the upper jaw were filled and 6 was further root-filled, a slight pain was registered at all bitings, and the values varied between 26 and 37 kg.

The highest values were obtained in a third case, where the figures were at 7 62 k., at 6 47 kg. and at the premolars 52 kg. At the front teeth was measured 32 kg., all measurements being made with a distance of 6 to 10 mm.

The present investigation comprises both a test material of 10 cases, selected according to a definite principle, a group of 36 students, 10 cases of periodontal disease and 10 cases of complete dentures (Chapter V).

Results of the measurements

10 test cases.

a) Occlusive biting in group Pb = 1.0 mm. Bite plane 7— to 4— and —4 to —7 (page 60)

The total force developed between the jaws is 65 kg., and it is evenly distributed on the right and the left side. No systematic difference is found. The difference found in some individual cases is caused by the variability of the force, the differences in the anatomical shape of the teeth and their relation to their antagonists, as well as by the manner of biting.

b) ***Occlusive biting by single teeth. Pb = 1.0 mm., and a comparison of results with Pb = 0.5 mm.*** *(page 61—63)*

The Tables show that the total force developed between the jaws is 66 kg. and is evenly distributed on both sides. No systematic difference is found. If a difference occurs it is due, as has already been pointed out, to the variability of the force, differences in the anatomical shape of the teeth, their position in relation to their antagonists, and to the manner of biting. The greatest force is developed at the second molar and is 33 kg., at the first molar it is 29 kg., at the second bicuspid 25 kg., and at the first bicuspid approximately the same as at the second.

In a comparison between the forces developed when a bite plane is used stretching from 7 to 4, and when biting is carried out by a single tooth, it is shown that the total force is of the same magnitude in both cases, namely 65—66 kg. It is also interesting to note that the force decreases towards the front and is least at the first bicuspid.

If one compares the maximum range of the force at the single teeth and at the different groups of teeth, there is still agreement. In general all the statements hold good which have been made in the description of the results of occlusive biting in group.

c) ***Occlusive biting in group. 36 cases. Pb = 1.0 mm.*** *(page 63—64)*

The suitability of the method was tested on a selected material, where the only requirement was that the teeth contacted each other within the dental arches and intermaxillarily in occlusion. It was also of interest to gain information of the force developed between jaws of varying sizes, varying forms, on a varying number of teeth with or without fillings. The material consisted of students of both sexes, 22—28 years of age.

Generally the statement holds good that the force developed is distributed in the same way as in the 10 test

cases, only the values are lower throughout. Thus the force measured at 7— is 13.2 kg. and at —7 13.1 kg., at 6— 6.2 kg. and at —6 6.8 kg., at 5— 3.1 kg. and at —5 2.9 kg., at 4— 3.5 kg. and at —4 3.3 kg. The total force on the right bite planes is 24.4 kg., on the left bite plane 25.3 kg., and the total force is 50 kg. The lowest and the highest value at 7— is 3.4 kg. and 35.3 kg., at —7 2.6 and 33.6 kg., at 6— and —6 0.5 and 20.0 kg. and 0.7 to 16.6 kg., at 5— and —5 0.6 to 10.4 kg. and 0.3 to 10.4 kg. The values at 4— and —4 are finally 0.4 to 13.3 kg. and 0.4 to 11.3 kg. On the right bite planes the values are 5.7 to 66.3 kg., on the left 2.5 to 48.8 kg., and the total force varies between 8.2 and 100.9 kg.

In calculating the force in cases of periodontal disease a simplified form of the method has been used (Chapter VI).

As local symtoms and diseased areas have varied to such an extent that a comparison has been impossible, each case has been individually described.

The distribution of the force on the right and the left side at the different teeth is shown in the Table. The greatest force is developed at the second molar, 17.6 kg. on the right side and 19.5 on the left. At the first molar a force only a little over half as great is registered, 9 kg. on the right side and 8.4 kg. on the left. At the two bicuspids the values of the developed force decrease markedly. At the second bicuspid the measurement is thus on the right side 3.5 kg. and on the left 2.4 kg. At the first bicuspid the figures are 3 and 2.7 kg.

The maximum variation at the different teeth and groups of teeth is shown in column 4. The lowest and highest values are at the second molar 10.9 kg. and 26.6 kg., at the first molar 3.5 and 21 kg., at the second bicuspid 0.9 and 6.0 kg., and at the first bicuspid 0.9 and 5 kg.

The mean value of the force developed from 7 to 4 is 32.5 kg. ± 1.8, with the lowest value 24.4 kg. and the highest value 46.2 kg.

The mean value of the total force from 7 to 7 is 65 kg. with a range of 55.4 to 89.5 kg.

When biting was carried out on bite planes of 0.5 mm's thickness the results were of the same magnitude. No significant difference was found between the values obtained by biting on bite planes of 0.5 or 1 mm.

The same method of calculation has been employed in the cases of complete dentures. The bite planes comprise all teeth, thus also the front teeth. (Pb = 0.5 mm.)

The measurement has included occlusive and protrusive biting.

The following results were found: —

In occlusive biting impressions were seen only in the region of the second molar as far as the first bicuspid. The force is evenly distributed on both sides, and the mean value of the total force is 20.4 kg. The lowest and highest values are 7.1 and 36.8 kg.

In occlusive biting with complete dentures only 27.8 % of the force exerted in normal cases was developed. The difference is significant.

In protrusive biting impressions are obtained partly of the front teeth and partly of the molar regions of both sides. The force is equally distributed in all three regions, the average value of the total force being 22.7 kg. The lowest and highest values are 9.1 and 50.1 kg.

The investigation further comprises examinations of the curvature radii of the cusps (page 42—44) and the hardness number of lead (page 38—42).

The suitability of lead has been established by check measurements (page 47—49, Diagram 5) and by Meyer's relation (page 51—53, Diagram 6).

SUMMARY

The main purpose of the present investigation was to *construct an apparatus* registering the exact force developed between the jaws.

In measuring the force by biting according to physiological requirements (Chapter II), the apparatus should be constructed in such a way that it causes no change in the physiological courses of movement of the jaw joint and the mandible.

The measurement takes place in an area between the jaws which is defined by the rest position and the position when the teeth make contact in central occlusion.

The thickness of the apparatus must, as a consequence of this, be less than the space between these points.

Within this space biting takes place at the closing movement in the axial or vertical direction of the tooth. "It is in this direction that the root, the fascicular system of the root tissue, the hydraulic apparatus in the vascular system for equalisation of the pressure load, as well as the architectonic shape of both alveolar and basal jaw bone, are all adapted and formed."

Within this space biting takes place at the end phase of biting, i. e. in the direction parallel with the resultants obtained when the parallelograms of force of the biting muscles are combined.

There is also a possibility of determining the force in protrusive biting. No other phases of the articulation movements are possible to measure. Simultaneous registration of both sides of the jaw is a condition for obtaining measurements which are physiologically acceptable.

The construction of the measuring apparatus (Chapter III) was based on the working hypothesis that the measuring apparatus must register the forces of individual teeth and individual cusps. The first attempts were aimed at producing an instrument for extraoral measurement, i. e. a bite plane between the teeth and a registration scale ex ore showing the total force and the individual force of each cusp.

The first apparatus was based on the variations of resistance in layers of carbon dust. The second investigation dealt with the variations of capacity in a plate condenser. In the third attempt the solution was sought for in the inductive (magneto-elastic) method by means of coils on metal rods with special magnetic properties. This construction necessiated a precise indication of the highest point of each cusp for exact fitting of the rods. The problem was solved by stereometric mapping of jaws and teeth with contour curves and characteristic high and low points, which gave the constructor an accurate map for the application of the apparatus.

Apart from these experiments the possibility has also been discussed of equipping different sections, each comprising one cusp, with rubber balloons containing air or liquid, and measuring the force developed in atmospheres.

All these experiments however proved that it is at present impossible to construct an apparatus in accordance with physiological requirements. The varying forms and extensions of jaws, teeth and cusps render the construction of a universal apparatus impossible.

The possibility of constructing an apparatus for *intraoral* measurement then became the object of investigation.

Intraoral measurement is based on the Brinell test, i. e. the test used in metallurgy for mechanical testing of the hardness of a metal.

After a critical survey of results obtained before it was decided that the bite planes must be of such a dimension

that 1) the physiological requirements are fulfilled, 2) each impression is measurable, 3) the composition of the bite planes makes occlusive biting possible without metal plates or steel pellets, 4) the bite planes are moulded to the anatomical shape of the teeth, and 5) the impressions can be calculated by a mathematical formula.

Different metals were tried for the purpose with the result that stamped out lead plates were found to fulfil the requirements.

The bite planes were made in two thicknesses, 0.5 mm. and 1 mm.

For measuring the occlusive force in the normal cases, the cases of periodontal disease, the bite planes were made to extend over groups of both bicuspids and molars and also over single teeth.

For measurement of occlusive and protrusive biting in cases with complete dentures bite planes were punched to cover the whole set of teeth. All bite planes were made for the teeth in the lower jaw.

Method of measuring (Chapter IV). To determine the exerted force, when the cusps are pressed into the bite plane and leave permanent impressions, the following points have to be determined: a) the degree of hardness of lead, b) the curvature radii of the cusps and c) the shape of the impressions.

The hardness and elasticity of lead are slight, while its plasticity is considerable. On account of these characteristics lead has little resistance to permanent deformation, and thus lacks the ability to recover its original shape when the deforming force ceases. Its plastic capacity is on the contrary great, i. e. the capacity to keep the particles of the material together in spite of deformation.

The action of biting causes a deformation in the lead plates in those places where the cusps of the upper jaw teeth are pressed in and impressions of various sizes are made according to the anatomical shape of the teeth.

a) *The determination of the degree of hardness of lead (the constant of force).*

As the Brinell number of a material represents the limit of its elasticity and the point at which permanent deformation is caused, the knowledge of the degree of hardness of lead makes it possible to determine the force employed.

The Brinell test is carried out by means of a steel ball of a given diameter being forced against the surface of a material with a given pressure.

The hardness is stated as being the pressure H_B on the contact surface between the ball and the object, i.e. the quotient P/A of the pressure load P and the surface area A of the Brinell impression.

The determination of the constant H in the term $P = H \cdot A$ (P = the force, A = projected surface of the impression) was carried out by loading pellets of a certain diameter with known weights, whereafter the projected surface of the impression obtained was measured by microscope. The relation between the load used and the surface was calculated, and this relation equals the sought constant of force H.

According to the The Swedish Metallograph Society's handbook of hardness, published by Wretblad, the absolute surface area A_o of the Brinell impression is difficult to measure, and is therefore seldom used as a basis for determining the hardness number.

In its place either a spherical surface, approximately equal *to* A_o, is used, or the projection of A_o in the plane of the object surface, e. g. a circle area A_c.

In order to obtain information as to the order and value of the constant of force (hardness number H) under varying loads and varying times of loading, experiments were made, which showed that the constant of force varies according to the variation in diameter of the pellet, thickness and treatment of the lead plate, as well as in the time of loading.

A comparison between the magnitude of the constants of force, in the use of projected surface and spherical surface, showed that the constant of force decreases as the pellet diameter increases.

In this investigation the calculation of the hardness number has been based on the projected surface of the impression.

b) *Measurement of the curvature radii of the cusps.*

The curvature radii are obtained through profile projector measurements of vertically cross-cut cusps of plaster models.

c) *The shape of the impressions.*

The shape of the projected surface of the impressions made by plastic deformation has been ideally described as an ellipse. The following test was made in order to gain information whether this simplification in description causes error in the calculation of the surface and consequently also in the calculation of the force developed.

Amalgam models were made of groups of bicuspids and molars in both sides of the upper jaw. Lead plates of 1 mm's thickness were treated according to the same principles as the bite planes.

These models served as impression objects in a Vickers apparatus and the load was between 2.5 kg. and 42.5 kg. The two impression diameters at right angles were measured in a microscope. The curvature radii of the cusps were measured in a profile projector, and the constant of force of the lead (hardness number) H was calculated.

From this diagram the value was obtained of the constant of force at the various cusps, and the force P was determined according to the formula

$$P = \frac{\pi}{4} \cdot d \cdot d_1 \cdot H$$

The investigation comprised 13 different loadings, and each loading included 2 to 6 tests. Altogether 58 tests were carried out. The inclination of the model in relation to the lead plate was varied, and individual cusps were also loaded in each test.

A comparison between the force used and measured is illustrated by Diagram 5.

From a comparison of the two curves it is evident, that no systematic error occurs, which is a proof that the method is reliable for the calculation of the force developed.

d) *Determination of the force by measuring the depths of the impressions.*

In this investigation the depths of the impressions have been observed by determining the curvature radii of the cusps, but attempts have also been made to measure the depth itself.

A number of impressions were measured with a Schmaltz's light ray microscope. Only the biggest and deepest impressions were possible to measure, and the degree of exactitude was necessarily low on account of the position of the impressions on undulating surfaces. The same was the case when measuring with a Woxén surface indicator. The needle penetrated the material, and the registration only suggested, and did not mark with exactness, when the impression commenced and when it ended.

From the measurements, however, the information was gained that the depth of the impressions was on an average about the limit indicated by Wretblad as the point where the underlying material cannot influence the result.

e) *Meyer's relation.*

An investigation of Meyer's relation has been included in order to determine the suitability of lead (page 51—53, Diagram 6).

Practical application of the method of measuring (Chapter V.)

The investigation comprises both a test material of 10 cases selected according to a certain principle, a group of 36 students, 10 cases of peridontal disease, and 10 cases of complete dentures.

The measurements comprise occlusive biting, both on bite planes of a group from 7 to 4 and by single teeth (7, 6, 5, 4). The shape of the impressions has been determined from the cusps of the upper jaw, the curvature radii of which have ebeen measured in a profile projector. The hardness number of lead has further been determined, and the force P calculated.

Measurement of the force by biting in cases of peridontal disease and in cases of complete dentures.

In order to simplify the method of calculation an investigation was made showing that a curvature radius of 1 mm. and a corresponding hardness number can be used in calculation of the force. To the values obtained is added an error of about $\pm$ 5—10 %, which can be considered to lie within reasonable limits for odontological requirements, with regard to the apparatus for suspension of the teeth, the shape of the jaws and the jaw joint with its suspension.

The two groups have been treated in accordance with this method.

Comparison between earlier intraoral measurements and the author's own measurements. (Chapter VI.)

In this chapter an account is given of the fundamental difference between the apparatus of previous authors and the present construction as well as of the physiological premises for measurement.

Finally the author's own results are compared with those of earlier investigators.

LITERATURE

Angle, Edward H. — St. Louis. — Die Okklusionsanomalien der Zähne. Verlag von Hermann Meusser, Berlin, 1913.

Bernklau, K. — Herford. — Ist der Habersche Kaudruckmesser ein Präzisionsinstrument. Dtsch. Zahnärztl. Wochenschrift, 1932. Nr. 23/24.

Black, G. V. — Chicago. — Die Kaukraft und Ihre Beziehung zur Widerstandsfähigkeit und Gesundheit der Wurzelhaut. Konservierende Zahnheilkunde I. Verlag von Hermann Meusser, Berlin, 1914.

Blomgren, Erik, and *Ingelmark, Bo E.* (1948) An apparatus for the measurement of pressure, especially in human joints, Upsala Läkarfören. Förhandl. N. F. Bd LIII. Häft. 1—2.

Boos, R .H. — Minneapolis. — Intermaxillary Relation Established By Biting Power. J. A. D. A. 1940, August. Volume 27. Number 8.

Dahlberg, L. — Uppsala. — The masticatory effect, Diss. 1942.

Diedrich, F. — Stuttgart. — Die Kaudruckmessung und Ihre Notwendigkeit in der zahnärztlichen Praxis. Zahnärztl. Rundschau, 1928. Nr. 13, 14.

Eckermann, R. — Malmö. — Physiologische Bedeutung der Kieferbelastung und ihre Ermessung. Dtsch. Monatschrift für Zahnheilkunde, 1911. Nr. 9.

Engström, J. — Stockholm. — Handbok i Dental Laboratorieteknik. Del IV. Sveriges Tandläkarförbunds Förlagsförening, Stockholm, 1947.

Etling and *Köhler.* — Darmstadt. — Über den Kaudruck und eine neue Methode zu seiner Messung. Zeitschrift für Stomatologie. 1922. Nr. 3.

Goldberg, L. — Stockholm. — Individual Variability in Response to Local Anesthetics. Svensk Tandläkare-Tidskrift 1947. H. 6.

Gottlieb, B. — Wien. — Die Veränderungen der Gewebe bei übermässiger Beanspruchung der Zähne. Verlag von Georg Thieme, Leipzig, 1931.

Greve, Karl — Breslau. — Der Habersche Kaudruckmesser, Dtsch. Monatschrift für Zahnheilkunde, 1926. Nr. 17.

—»— Schlussbemerkungen auf Habers Entgegnung zu meiner Prüfung seines Kaudruckmesser. Dtsch. Monatschrift für Zahnheilkunde, 1926. Nr. 23.

Gysi, A. — Zürich. — Some Essentials to Masticating Efficiency in Artificial Dentures, The Dental Digest, New York 1920,1921.

—»— Studies on the Leverage Problem of the Mandible, The Dental Digest, New York, 1921. Nr. 1, 3, 4.

Haber, Gustav — Berlin. — Kaudruck — Messapparate. Zahnärztl. Rundschau 1926. Nr. 7, 8, 9, 12, 45, 48. 1927. Nr. 28.

—»— Die Aufgaben der Kaudruckmessung und der Zahndruckprüfung, Berlin, 1926. Verlag von Dr. Haber.

—»— Der Habersche Kaudruckmesser (Entgegnung der Arbeit von Greve). Dtsch. Monatschrift für Zahnheilkunde, 1926, Nr. 23.

—»— Die Zahnwurzel als Stützpunkt der Prothese, Berlin, 1926. Verlag von Dr. Haber.

Heinroth, Hans — Halle. — Kaudruckmessung, Fortschritte der Zahnheilkunde 1927, III, 1928, IV, 1929, V.

Hildebrand, G. Y. — Stockholm. — Studies in the masticatory movements of the human lower jaw, 1931, Verlag von Walter de Gruyter & Co, Berlin und Leipzig.

Holm, R. — Stockholm. — Electric contacts, Gebers förlag, 1946.

Horwáth — Budapest. — Die Rolle und Bedeutung des Messens der Kaukräfte in der Orthodontie. Dtsch. Monatschrift für Zahnheilkunde 1928, Nr. 9.

Ingelmark, Bo E., and *Erik Blomgren* (1948) An apparatus for the measurement of pressure, especially in human joints, Upsala Läkareförens. Förhandl. N. F. Bd LIII. Häft. 1—2.

Kampf, W. — Spandau. — Ist der Intensität des Kaudruckes für die oberen und unteren Zähne die gleiche? Zahnärztl. Rundschau 1927, Nr. 21.

Karlström, S. — Gävle. — Physical, Physiological And Pathological Studies of Dental Enamel With Special References To The Question Of Its Vitality. Svensk Tandläkare-Tidskrift 1931. Supplement nr 1.

Kazis, Harry — Boston. — Planning and Treatment for Bite Raising, Dental Items of Interest Publishing Co. 1943.

Köhler and *Etling.* — Darmstadt. — Über den Kaudruck und eine neue Methode zu seiner Messung, Zeitschrift für Stomatologie, 1922, Nr 3.

Lindblom, Gösta — Stockholm. — I S:ta Appolonias våld, Stockholm, Nord. Bokhandeln 1946.

Morelli, G. — Budapest. — Über Kaudruckmessung. Zahnärztl. Rundschau 1928, Nr. 7.

Müller, Max — Hannover. — Grundlagen und Aufbau des Artikulationsproblemes im natürlichen und künstlichen Gebisse. Verlag von Werner Klinkhardt, Leipzig, 1925.

Münzesheimer, Fritz — Berlin. — Ergebnisse aus Messversuchen mit dem Haberschen Kaudruckmesser. Zahnärztl. Rundschau 1927. Nr 27, 29.

Port and *Euler* — Heidelberg. — Erlangen. — Lehrbuch der Zahnheilkunde. Verlag von J. F. Bergmann, Wiesbaden, 1915.

Posselt, U. — Malmö. — Kompendium I Parodontologi. Köpenhamn 1946. W. Hellesens Förlag.

Puttkammer — Wismar. — Lässt sich mit der Kaudruckmessung die Tragkraft eines Zahnes oder eines Prothesenteiles bestimmen? Zahnärztl. Rundschau 1928. Nr. 28.

Riechelmann, Otto — Beitrag zur Systematischen Prothetik. Verlag von Hermann Meusser, Berlin, 1920.

Schoenbeck, Fr. — Berlin. — Zahnärztliche Werkstoffkunde. Verlag Barth, Leipzig, 1942.

Schröder, Hermann — Berlin. — Lehrbuch der technischen Zahnheilkunde. Verlag von Hermann Meusser, Berlin, 1927.

Strenger, Folke — Stockholm. — Praktisk tillämpning av stereometrisk mätning, Svensk Tandläkare-Tidskrift 1946, Nr. 1.

Sundberg, Stig — Västerås. — Om paradentosens etiologi och terapi. Odontologiska Föreningens Tidskrift 1946, Nr. 2.

Swenson, M. G. — New York. — Complete Dentures, The C. V. Mosby Company, St. Louis, 1940.

Tham, Percy — Stockholm. — Fotogrammetriska Mätmetoders tillämpning inom odontologien, Svensk Tandläkare-Tidskrift 1946, Nr. 1.

Tholuck, H. J. — Frankfurt a/M. — Der Kaudruck, Deutsche Zahnheilkunde, 1923, Nr. 59.

Thourén, Gotthard — Stockholm. — Eine Studie über das normale Gebiss, die Artikulationsgesetze sowie die Konstruktion der ganzen Prothese, Odont. Tidskrift 1910, Nr. 2.

—»— Om det s. k. "normala" permanenta ortognata bettet. Odontl. För. Tidskrift 1941, Nr. 1.

—»— Om det "normala" bettets occlusion. Odontl. För. Tidskrift 1941, Nr. 1.

—»— Om underkäkens rörelse dorso — ventro — dorsalt. Odontl. För. Tidskrift 1942, Nr. 3.

—»— Om underkäkens rörelse cranio — caudo — craniellt. Odontl. För. Tidskrift 1943, Nr. 1.

—»— Om underkäkens rörelse medio — latero — medialt. Odontl. För. Tidskrift 1944, Nr. 2.

—»— Om artikulationslagar och tuggningsrörelser. Odontl. För. Tidskrift 1944, Nr. 3.

—»— Om tuggtryck och intermaxillär muskelkapacitet. Odontl. För. Tidskrift 1946, Nr. 3.

Widman, L. — Stockholm. — Om tuggtrycket som etiologisk faktor vid Pyorrhaea alveolaris. Svensk Tandläkare-Tidskrift 1920, H. 5.

Wikblad, Å. — Göteborg. — Bettanalys vid marginal paradentit. Odontologisk Tidskrift 1943, Nr. 4.

Winkler, Rudolf — Friedberg — Hessen. — Der funktionelle Bau des menschlichen Kieferapparates. Dtsch. Zahnheilkunde 1922, Nr. 55.

Wretblad, P. E. — Fagersta. — Bestämning av Metallers Hårdhet. Verkstäderna 1945.

—»— Svenska Metallografförbundets Hårdhetshandbok.

Wustrow, Paul — Würzburg — Physikalische Grundlagen der zahnärztlichen Platten- und Brückenprothese, Band 1. Verlag von Hermann Meusser, Berlin 1919.

—»— Klinik der Plattenprothetik. Verlag von Georg Thieme, Leipzig, 1932.

Zerkowitz, O. — Berlin. — Ist der Habersche Kaudruckmesser ein Präzisionsinstrument bzw. ist er zuverlässig? Zahnärztliche Rundschau 1933, Nr. 10.

CORRIGENDA

Diagram 2, page 41, should be as follows:

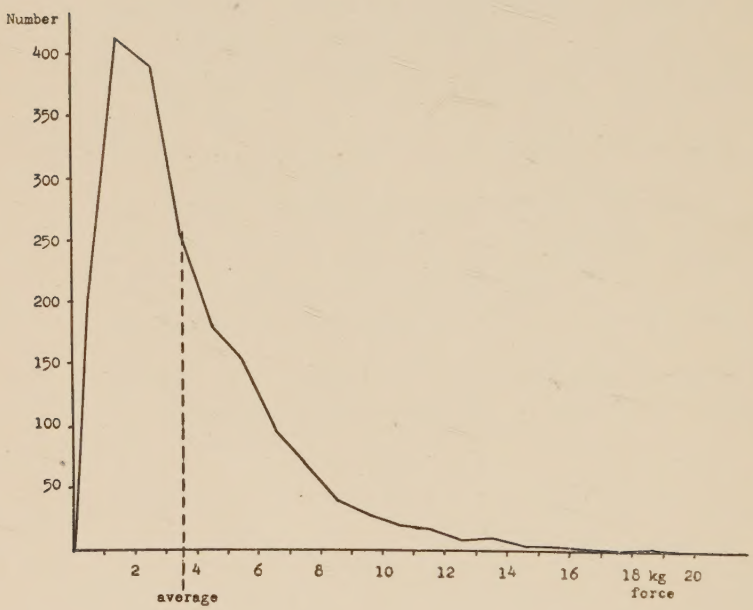
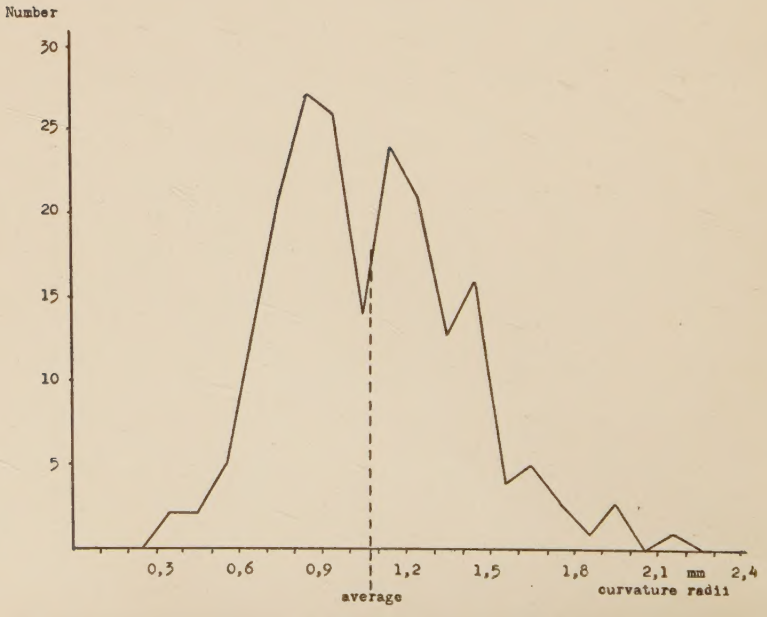


Diagram 3, page 43, should be as follows:



Stockholm
A.-B. Fahlcrantz' Boktryckeri
1 9 4 9